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**DELTA-OMEGA STABILIZER  
BRUCE 'A' GS**

Report No 87-12-K

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ABSTRACT

Power System Stabilizers based on the direct measurement of changes in turbine-generator shaft speed have been in service on the Bruce 'A' units since 1976. Recently, these stabilizers have been equipped with Transient Stability Excitation Control circuits and Dynamic Test Facilities. The old manual on these stabilizers has thus been superseded. This new edition covers the design, operation, maintenance procedures and modelling of the  $\Delta\omega$  stabilizer and all the added features.

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## SECTION 1

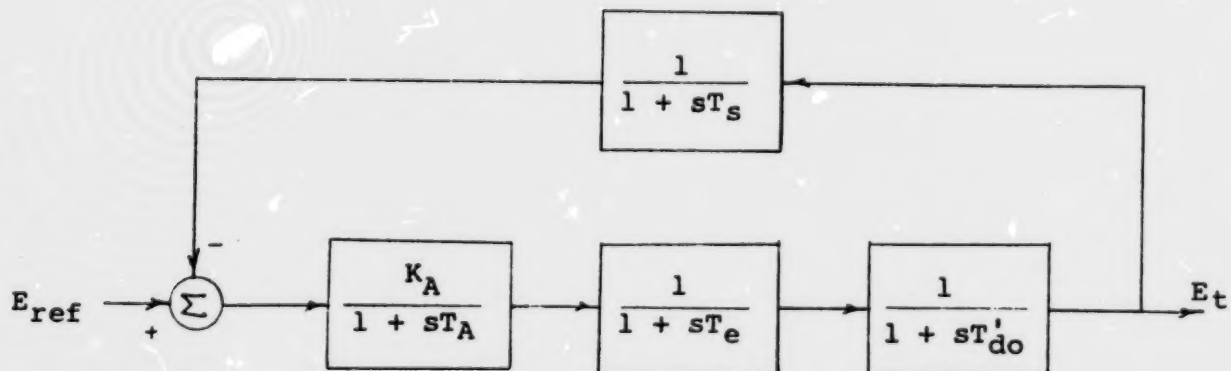
### GENERAL DESCRIPTION AND DESIGN CONSIDERATIONS

#### 1.0 BACKGROUND

Originally, terminal voltage of a synchronous generator was maintained by manual adjustment of the generator field voltage through an excitation regulator. When this loop was closed so that excitation was automatically controlled to maintain a set terminal voltage, the Automatic Voltage Regulator (AVR) was born. While this is still the main control loop, excitation of the synchronous machine is also varied in response to other signals which may augment or override the AVR signal. This group of signals is often referred to as Supplementary Excitation Control. The Power System Stabilizer is one such signal which acts through the excitation regulator to improve system dynamic stability. The Delta-Omega Stabilizer is a power system stabilizer developed by Ontario Hydro which uses turbine-generator shaft speed as its input.

From transient stability considerations, it is desirable that the magnetic flux of the synchronous generator be boosted as rapidly as possible for a drop in generator terminal voltage (eg, system fault). In other words, it is desirable to have a high gain voltage regulator loop with small time constants and high ceilings.

In conventional rotating exciter systems the response of the system is limited by the inherent time constants in the voltage regulating loop and the resulting gain limitations if the loop is to be stable. A simplified block diagram of an excitation system with the generator open circuit is shown below for reference.



In thyristor type excitation systems, the exciter time constant  $T_e$  (~1 s for rotating exciters) is usually negligible and the regulator time constant  $T_A$  is usually negligible as well. Because these time constants are small, the loop gain can be substantially increased. The result is a much faster response contributing to improved system transient stability limits.

While the high response excitation system improves transient stability, it unfortunately has the side effect of reducing the damping of oscillations of the machine against the power system.

The equation which describes the behaviour of the machine angle for small changes about a steady-state operating condition is of the form:

$$K_1 \frac{d^2 \Delta \delta}{dt^2} + K_2 \frac{d \Delta \delta}{dt} + K_3 \Delta \delta = \Delta T_M$$

where

$\Delta T_M$  = change in turbine input power  
 $K_3$  = synchronizing torque coefficient  
 $\Delta \delta$  = change in machine angle  
 $K_2$  = damping coefficient  
 $K_1$  = accelerating torque coefficient

$\frac{d \Delta \delta}{dt}$  ( or  $\Delta \omega$ ) = changes in shaft speed

$\frac{d^2 \Delta \delta}{dt^2}$  = shaft acceleration

In the case where the machine is fed with constant excitation,  $K_2$  is positive. The principal components of this factor are turbine damping and load damping. With a high speed exciter, however, it can be shown that this term can reverse sign under some system conditions/1/. This means that the damping can go from some positive value where oscillations will die out, to a negative value where these oscillations will grow. It then becomes necessary to provide a signal which will ensure that this term cannot go negative. In practice, by means of a power system stabilizer, it is maintained at a positive value which will give substantial damping.

There are several ways of generating such a power system stabilizing signal/2/. Only that using direct shaft speed as an input is discussed in this report.

From the above equation it should be evident that, to improve damping of the oscillations it is necessary to produce a torque which directly opposes shaft speed changes. There are two ways that such a torque might be generated:

1. The mechanical torque to the turbine could be modulated by means of the governor. This would require very fast and continuous control of governor valves. This method turns out to be impractical for the frequencies of oscillation under consideration.
2. The electrical torque could be modified by means of the field circuits for the frequencies of interest (remembering that electrical torque change introduced through the field must approach zero at very low frequencies).

Power system stabilizers employ this second method of changing torque. The stabilizer changes the field voltage of the machine as a function of speed changes. As there is some delay or time constant between a field voltage change and the resulting magnetic flux change, some phase lead or derivative component is required. Since the derivative of speed is acceleration, this signal may be thought of as comprising a speed and acceleration component. This speed and acceleration signal is "washed out" or reset so that the stabilizer does not modify the terminal voltage for slow or steady state speed (frequency) changes.

Power system stabilizers are discussed in greater detail in references listed at the end of this section.

### 1.1 Principle of Operation

Power system stabilizers, particularly those based on the direct measurement of turbine-generator shaft speed changes (Delta-Omega) have been used extensively on the Ontario Hydro System/1-5/. Stabilizers are required for dynamic stability whenever the high speed of thyristor excitation systems is exploited for transient stability improvement.

The Delta-Omega stabilizer is part of a control loop which modifies excitation of the generator as a function of changes in rotor speed and acceleration. By controlling the excitation in an appropriate manner, it is possible to provide a torque to oppose the changes in generator shaft speed (over a limited frequency range) and hence enhance the damping of the machine vs system and inter-area modes of oscillation. The effect is analogous to the introduction of a shock absorber or a dashpot into a mechanical system.



The stabilizer affects only the hunting or oscillation of the unit with respect to the system. It has no effect on the steady-state speed. The system is quite independent of the speed regulation provided by the turbine governing system.

Figure 1-1 shows a functional block diagram of the Delta-Omega stabilizer and terminal voltage limiter. The Optional Transient Stability Excitation Control (TSEC) and dynamic test facilities are omitted from this diagram. The device provides a voltage input to the excitation regulator proportional to changes in generator shaft speed (plus some derivative component).

Two speed signal generators are employed, one located between each pair of LP cylinders as shown. At each location, 15 slots are milled in the shaft. Two diametrically opposed electromagnetic pickups are employed to generate pulses as these slots go by. A tachometric circuit then produces a voltage level proportional to the rate at which these pulses appear.

Outputs of the tach circuits associated with the two speed wheels are then added in the appropriate proportions. A reset circuit (high pass filter) blocks the steady-state level and only changes in speed are transmitted to the next stage. These speed changes are amplified and some phase lead (acceleration component) is added. By choosing the right proportions of the speed signals from the two locations, excitation of torsional modes of shaft oscillation is precluded.

As an added precaution, a filter has been included to attenuate torsional frequencies if they should occur. The resulting signal is used to modify the terminal voltage reference of the excitation regulator which in turn, through the generator field, provides a damping torque for rotor swings.

The stabilizer is in service only when the generator is connected to the power system.

## 1.2 Design Considerations

In many respects, the stabilizer for Bruce GS is similar to those supplied for the Lambton GS, Nanticoke GS and Lennox GS/3, 4, 5,/. Analysis of the shaft torsional modes of oscillation, Figures 1-2, and subsequent eigenvalue analysis however, showed the torsional modes to be unstable without the torsional filter if speed was sensed at one location only/7/. In addition, the frequencies of the torsional modes were significantly lower than those on previous machines, making filtering more difficult.

In order to meet the design criterion of being torsionally stable without the filter in service it was necessary to use two speed wheels, one located between each pair of LP turbines. Logic was provided to remove the stabilizer from service for loss of any pickup signal.

Because the generator in the initial sytem configuration would not be stable at full load without the stabilizer in service, switching was provided to transfer to the alternate voltage regulator for stabilizer failure or opening of the signal switch.

### 1.3 Voltage Limiter

On all generating units provided with a power system stabilizer it has been customary to install a terminal voltage limiter circuit. In some stations the limiter is part of the static excitation system and none is provided with the stabilizer. Otherwise the limiting action is provided by the stabilizer. This card contains a voltage transducer which is also used when performing dynamic tests on the stabilizer and excitation system. A full description of the limiter circuit will be found in Section 4.8.

### 1.4 Transient Stability Excitation Control Circuit (TSEC)

The TSEC circuit/9/ was incorporated into the  $\Delta\omega$  stabilizer in 1984/85 to help improve the post fault transient stability of generators. Studies described in Reference 9 have shown that inter-area oscillations could be reduced following a fault if the excitation on the most affected units were held at a positive ceiling for a period of time longer than that provided by standard controls on exciters. The TSEC performs this function only for severe faults. A fault is assumed to have occurred when these three conditions are detected simultaneously by the TSEC:

- sudden drop in terminal voltage,
- field voltage at positive ceiling,
- positive speed change larger than a preset magnitude.

Once the logic of the TSEC has operated on the above conditions, a signal of the form

$$T(s) = \frac{K_{ANG}}{1+s \cdot T_{ANG}} \cdot \Delta\omega(s)$$

will be applied to the voltage regulator input. This signal will override the normal stabilizer signal and the input to the integrator is removed when either,

- the speed change goes more negative than a threshold value; or
- the exciter comes out of saturation.

The output of the integrator then decays with time constant  $T_{ANG}$ .

The value of  $K_{ANG}$  is chosen such that the field voltage is held at positive ceiling or the terminal voltage is held at its limit until the second swing of the machine versus system mode is reached.

Figure 1-4 is a functional block diagram representation of the TSEC circuit. The terminal voltage signal for the TSEC level detector is obtained from the terminal voltage transducer and limiter card. The speed signal is obtained from the speed input card of the stabilizer.

The voltage regulator output signal is used by the TSEC to monitor the field voltage since, in a static exciter with no transient gain reduction in the AVR, there is a 1 on 1 correspondence between the regulator output and the field voltage.

Logic is provided to activate a relay contact once the three conditions outlined earlier are satisfied. Limits are applied to the output signal prior to its summation with the stabilizer signal. ON/OFF switches are provided to remove the TSEC from service and also disconnect the AVR signal.

### 1.5 Protection Features

Protection circuitry causes the stabilizing signal to be removed and the voltage regulator to be tripped to the B regulating channel for:

- loss of any pickup signal
- failure of power supply
- turning off  $\Delta\omega$  signal switch with the unit on line.

The stabilizer is in service only when the generator is connected to the power system. This function is accomplished by a 'a' pallet switch from the unit breaker.

### 1.6 Dynamic Test Facilities

In 1980 a test procedure was designed to evaluate the performance of static excitation systems and power system stabilizers under dynamic conditions/10/. The procedure requires the recording of generator terminal voltage, power, field voltage and stabilizer output. Isolator circuits have been provided in the  $\Delta P_w$  stabilizer used in the 'B' regulating channel to allow easy connection of a recorder to monitor the quantities. A disturbance generator to apply step changes to the terminal voltage reference signal via the stabilizer is also provided. Reference 10 and Section 5.8 of this manual describe the procedure in detail and the dynamic test facilities are described in Section 4 of this manual.

### 1.7 Mechanical Details

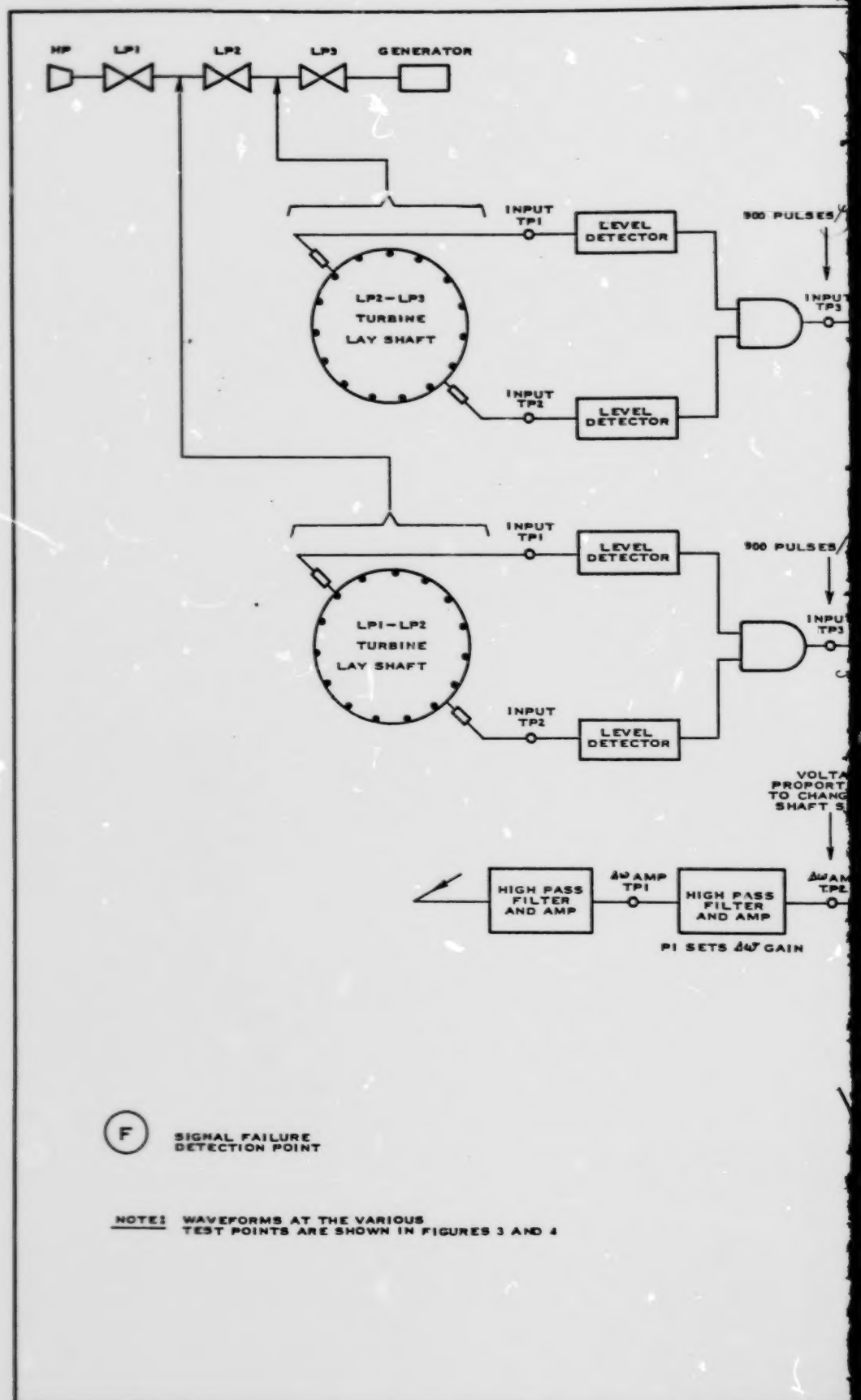
The  $\Delta \omega$  stabilizer circuits are assembled on 15 printed circuit cards installed in a double-walled, two-tier metal cabinet. The inner cabinet is electrically isolated from the outer cabinet for improved interference immunity. The outer cabinet is 48.3 cm wide, 30 cm high and 27 cm deep and with all the cards installed weighs 18.5 kg. All the cards are easily withdrawn from the front, including the power supply module.

Further information is provided in Section 5 on mechanical construction, electrical ratings, mounting arrangement and wiring techniques.

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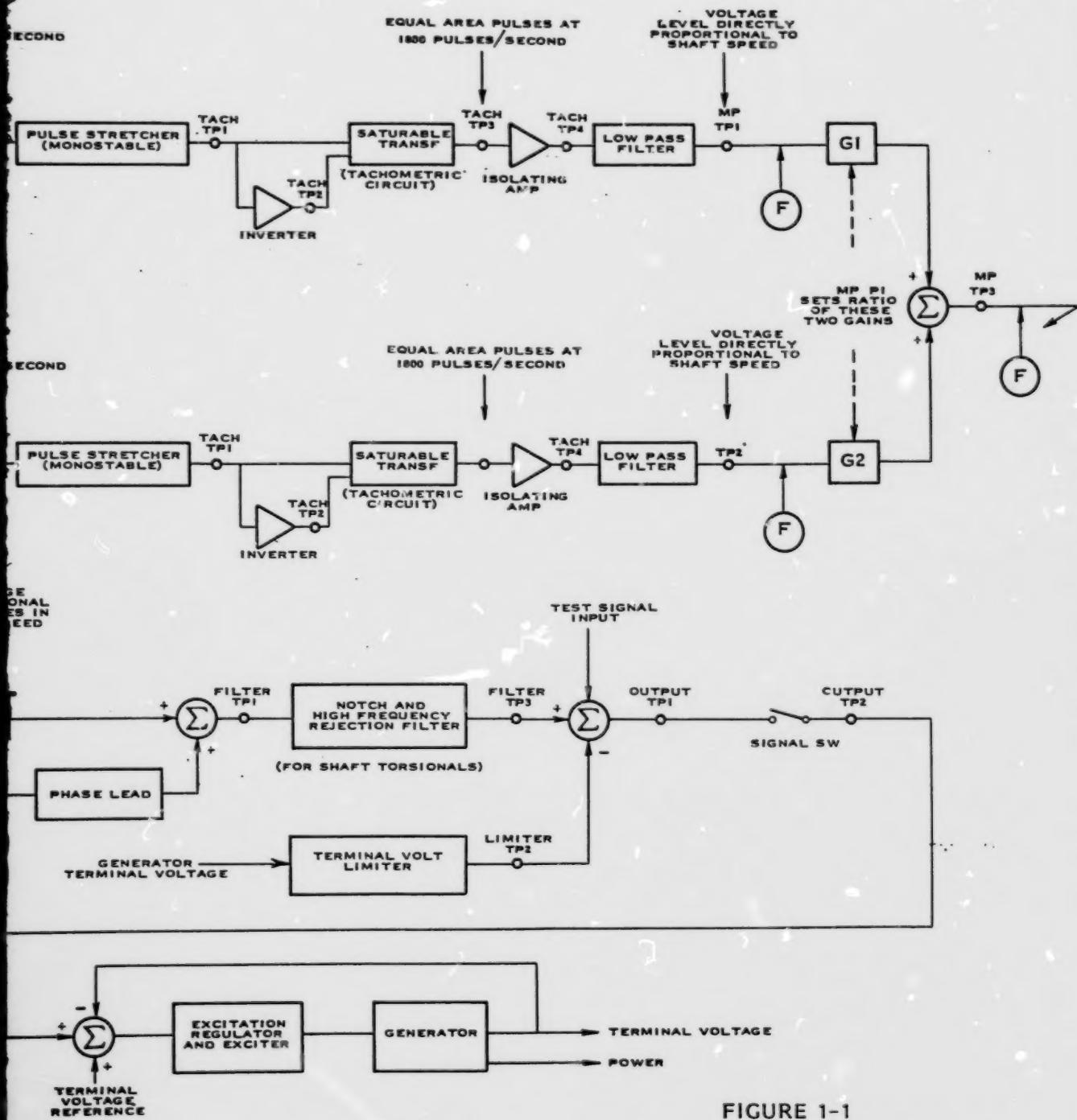


FIGURE 1-1  
BRUCE "A" GS - DELTA-OMEGA  
STABILIZER BLOCK DIAGRAM

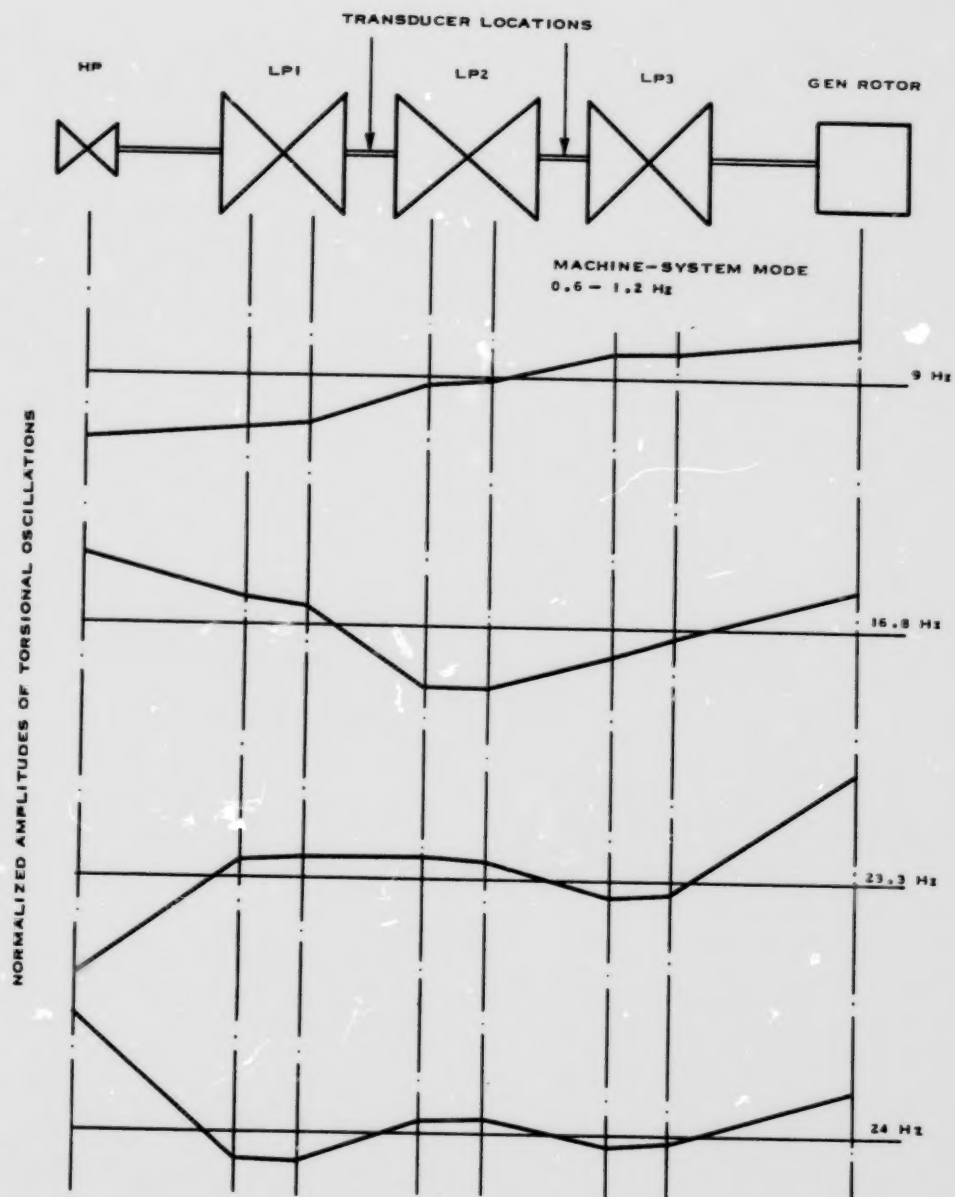
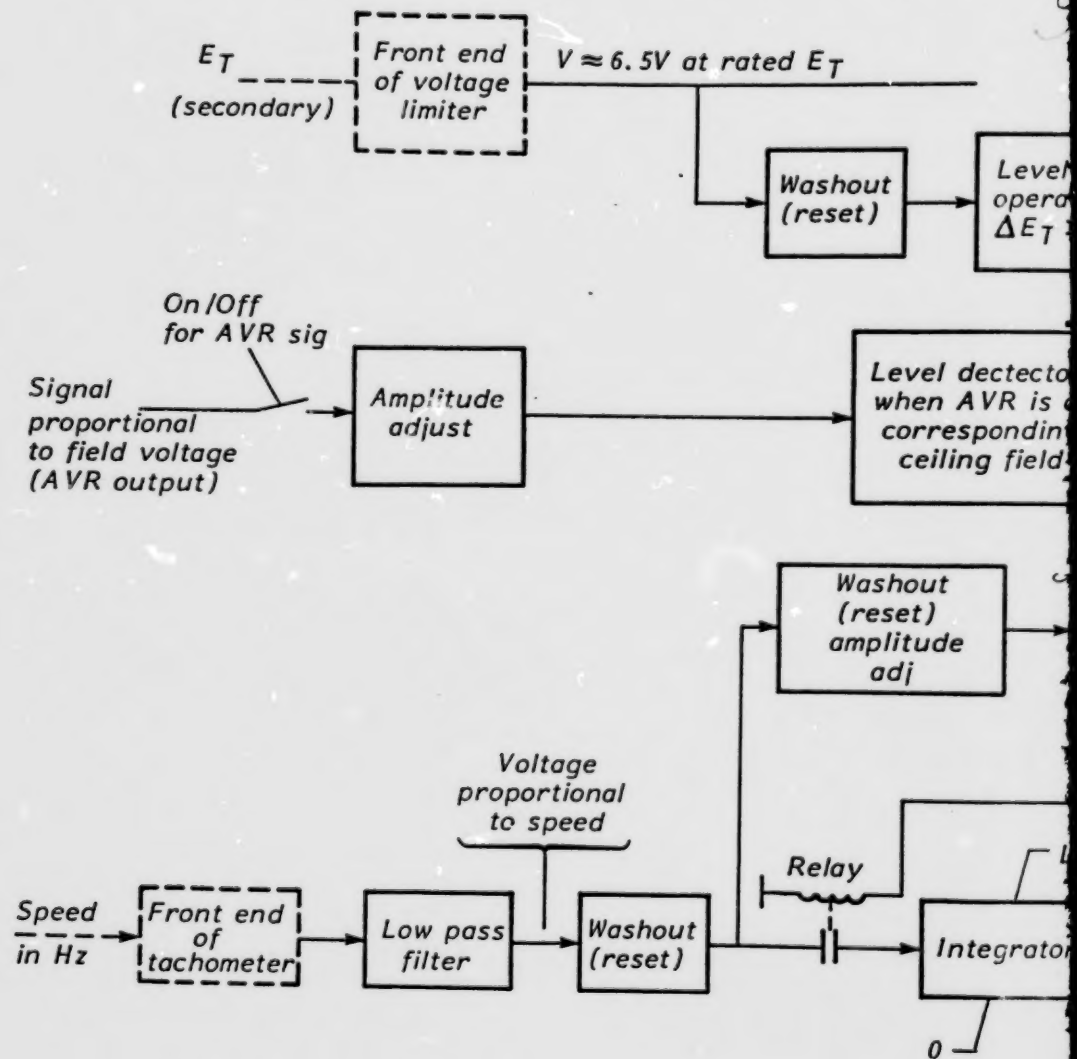


FIGURE 1-2  
PROFILES OF SHAFT TORSIONAL MODES OF OSCILLATION  
BRUCE "A" GS

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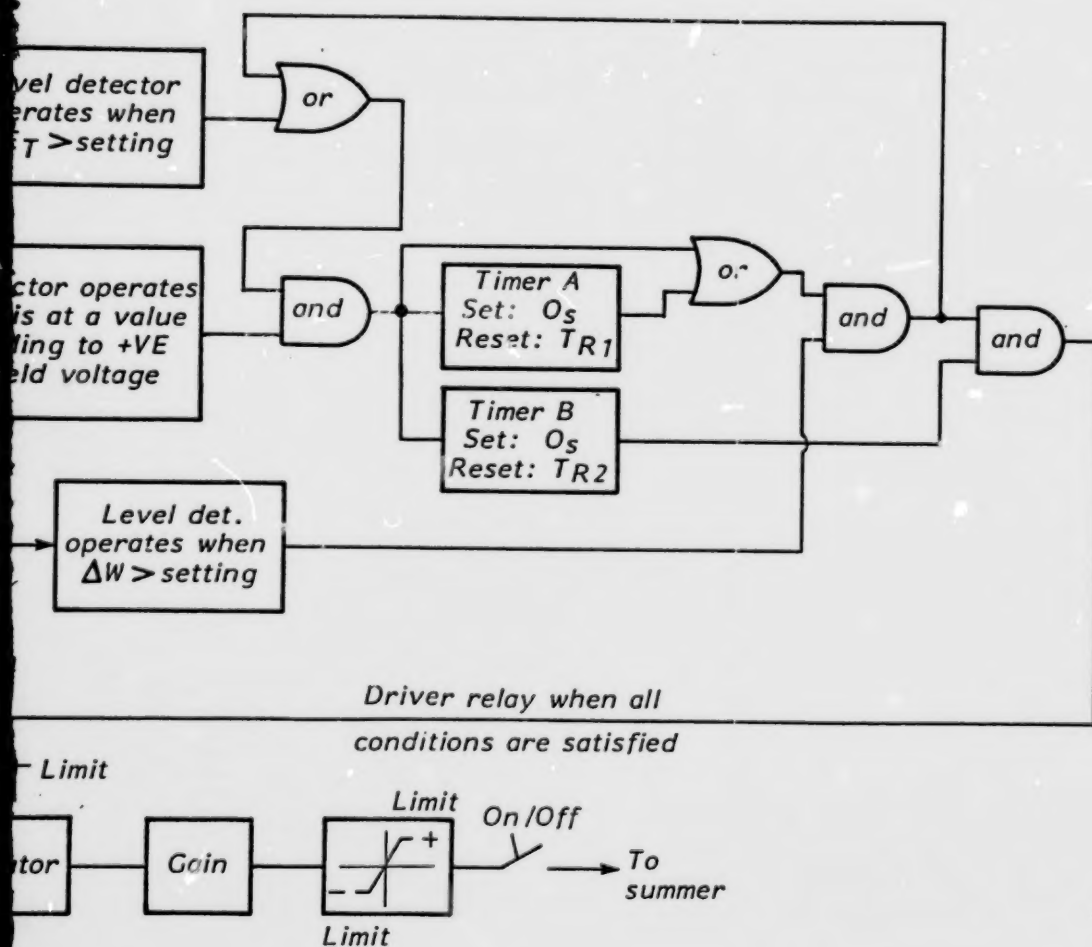


FIGURE 1-4  
FUNCTIONAL BLOCK DIAGRAM  
REPRESENTATION OF THE TSEC CIRCUIT

## SECTION 2

### OPERATING PROCEDURES AND SETTINGS

#### 2.0 GENERAL

Power system stabilizers are installed on generators to help maintain the dynamic stability of the units. Normally, there should be no need to remove the stabilizers from service, except for repairs. Maintenance is not required on this equipment while the generator is running, as it uses solid-state circuitry throughout and the cabinet provides protection against dirt and dust.

The stabilizer has been designed to block itself for internal failures and this situation is indicated by the operation of a relay contact wired to annunciate and possibly cause a transfer from the main Automatic Voltage Regulator to an alternate regulating channel.

#### 2.1 Operating Procedures

CAUTION: If the stabilizer fails in service or if it becomes necessary to remove the stabilizer from service, the unit stability may be affected. The loading of the unit must therefore be adjusted as required.

At stations equipped with dual automatic voltage regulators, the control of terminal voltage should be transferred to the alternate channel prior to removing the stabilizer from service. If an alternate automatic voltage regulator is not installed, the unit loading must be reduced to a level which will allow stable operation; it may be necessary to transfer the voltage control to manual.

To avoid a system disturbance, it is imperative that the following steps be followed when placing a stabilizer in or removing it from service while the generator is on line.

The No 1 procedure is recommended.

##### Procedure No 1 -

##### To place the stabilizer in service

- a) Make sure that the unit is on the alternate (B) voltage regulator or on manual control
- b) Check that the Signal Switch (located on the output card) is OFF.



- c) Switch ON the Power Supply Switch (located on the power supply card).
- d) Wait three minutes
- e) Switch ON the Signal Switch
- f) Balance the voltage regulator and return to "A" voltage regulator control.

To remove the stabilizer from service

- a) Transfer the voltage regulator to alternate (B) regulator control

It is recommended that the unit be operated in this mode (B AVR controlling) without the 'A' stabilizer in service.

Procedure No 2 -

If it is necessary for some reason to maintain AVR "A" control, the following procedure should be followed.

To place the stabilizer in service

- a) Block stabilizer malfunction/transfer contact
- b) Check that the Signal Switch (located on the output card) is OFF.
- c) Switch ON the power supply switch (located on the power supply card).
- d) Wait not less than 3 minutes
- e) Switch ON the Signal Switch
- f) Wait at least 1 minute
- g) Unblock the stabilizer malfunction/transfer contact.

To remove the stabilizer from service

- a) Block the stabilizer malfunction/transfer contact
- b) Switch OFF the Signal Switch (located on the output card)  
NOTE: This leaves the high gain "A" AVR in service and the unit may not be stable at high load levels in this configuration.

### To place the TSEC circuit in service

The Transient Stability Excitation Control (TSEC) circuit can only be placed in service after the stabilizer is already in service.

- a) Place the switch on the TSEC #2 card to the ON position.
- b) Wait at least 1 min for the circuits to stabilize.
- c) Measure the signals on TP1 to TP4 of TSEC #1 and TSEC #2. The signals must be:

|      | <u>ON TSEC #1</u> | <u>ON TSEC #2</u> |
|------|-------------------|-------------------|
| TP1: | +10 mV            | +15 V             |
| TP2: | +60 mV            | +15 V             |
| TP3: | <7 mV             | +15 V             |
| TP4: | <1 mV             | 0.0 V             |

- d) If all the signals on the test points have the correct value, turn the TSEC Signal switch ON.

### To remove the TSEC circuit from service

- a) Place the switch on TSEC #1 card to the OFF position.
- b) Place the switch on TSEC #2 card to the OFF position.

### 2.2 Use of Test Points

Several test points have been provided on the fronts of the cards to facilitate testing and troubleshooting. Test points on the white-faced cards are for dynamic test purposes, as discussed in Sections 4 and 5. The test points on the blue-front cards are not protected against accidental short circuits or noise pickup. Therefore, because of the sensitivity of the circuits and the high gains used, care must be exercised when monitoring the test points while the stabilizer is in service on a unit which is on line. Oscilloscopes and voltmeters must have a high input impedance and be isolated from the building ac supply ground (or differential inputs used). Leads to the test points must be kept short. Typical waveforms on the test points are shown in Figures 4-21 and 4-22.

### 2.3 Settings

The  $\Delta\omega$  stabilizer described in this report has been designed for use on the Bruce 'A' excitation systems. As such, settings have been applied by Research Division to match the unit requirements. Only the most important settings are reviewed here. This information may be useful if major maintenance is performed on the stabilizers by field personnel.

### 2.3.1 Input Card

The pulse width out of the monostable circuit must be set by P1 to:

$$\begin{aligned}\text{Pulse width} &= \frac{\text{Time for 1 shaft revolution}}{\text{No of slots} \times 2 \text{ pickups} \times 2} \\ &= \frac{0.03333}{15 \times 2 \times 2} \\ &= 0.556 \text{ ms.}\end{aligned}$$

### 2.3.2 Missing Pulse Card

The ratio of the signals from the two tach circuits is changed by turning pot P1. Though the ratio changes, the amplitude at TP3 remains relatively unchanged. With P1 = 50% the ratio of signal from the two speed wheels is unity. The output at TP3 as a function of P1 setting is approximately:

$$W(\text{TP3}) = (0.75 - 0.5 \text{ P1})W_1 + (0.25 + 0.5 \text{ P1})W_2$$

The selected ratio must be approximately the inverse of the ratio of the relative amplitude of the first shaft torsional at the two speed detection locations. Figure 1-2 shows the torsional profiles.

P1 must not be adjusted with the stabilizer in service

Provision has been made to allow the replacement of P1 with fixed resistors after initial system set up.

### 2.3.3 Delta-Omega Amplifier Card

Potentiometer P1 on the card sets the overall gain of the stabilizer. With the tach card gain, AVR input gain and other gains as set at Bruce 'A' NGS, the overall gain provided by P1 is:

$$\text{GAIN} = \text{P1} \times 56 \frac{\text{pu } E_t \text{ ref}}{\text{pu speed}}$$

where P1 = 0 to 1.0.

P1 has been set at 0.25 during the commissioning tests, for a gain of 14.

#### 2.3.4 Phase Lead Card

The phase lead card characteristic has the transfer function:

$$F(s) = \frac{1 + T_1 \cdot s + (T_2 + T_1 - 1) s^2}{1 + T_1 \cdot s + (T_1 - 1) s^2}$$

$$\begin{aligned} \text{where } T_1 &= 1.013 + 0.47 \cdot P_1 \\ T_2 &= (0.10 + 3.7 P_1) \cdot P_2 \end{aligned}$$

P1 and P2 vary between 0 and 1.0.

#### 2.3.5 Filter Card

The filter card components have been selected to provide a notch filter characteristic with the notch frequency at precisely 9 Hz. Any adjustment on this card must be checked with a frequency response analyzer to ensure that correct attenuation is maintained.

#### 2.3.6 Terminal Voltage Limiter Card

With the installation of TSEC facilities, the terminal voltage limiter card design was changed to provide a limiting action with minimal filtering but with hysteresis. Potentiometer P1-7 sets the limit start in volts on the PT secondary as per the formula below:

$$P1-7 = \frac{59}{E_t \text{ Limit Start in volts on PT secondary}}$$

A limit start of 12% to 15% above rated is normally used.

#### 2.3.7 Transient Stability Excitation Control Card - TSEC-1

The transfer function from the stabilizer input speed signal to terminal 9 of the TSEC1-1 card is:

$$H(s) = (3.82 \times 10^{-3} \times \frac{R29 + R30}{R30} \times \frac{R11}{10.7} \times \frac{s5.0}{1 + s5.0} \times \frac{R15}{5} \times \frac{1}{1 + s(R15 \times 4.7 \times 10^{-3})} \times \frac{R17}{10}) \text{ V/Hz}$$

where R11, R15, R17, R29 and R30 are in kilohms.

For a block diagram representation, the following relationships are used:

$$\begin{aligned} K5 &= (R29 + R30)/R30 \\ K1 &= R11/10.7 \\ K2 &= R15 \\ K3 &= R17/10 \end{aligned}$$

where R11, R15, R17, R29 and R30 are in kilohms.

The complete transfer function for the speed signal through the TSEC circuit is:

$$H(s) = (\text{Speed Wheel Freq} \times 3.82 \times 10^{-3} \times K5 \times \frac{K1 \cdot s5.0}{1 + s5.0} \times \frac{0.2 K2}{1 + s0.0047 K2} \times K3 \times 2.0 \times KR) \frac{\text{pu speed}}{\text{pu } E_t \text{ ref}}$$

This transfer function can be compared to the reduced expression:

$$H(s) = \frac{K_{\text{ANG}}}{1 + sT_{\text{ANG}}}$$

and the following relationships obtained:

$$K_{\text{ANG}} = \text{Speed Wheel Freq} \times 3.82 \times 10^{-3} \times K5 \times K1 \times 0.2 \times K2 \times K3 \times 2.0 \times KR$$

$$T_{\text{ANG}} = 0.0047 K2$$

(Note: In the frequency range of interest, 0.2 to 3 Hz, the term  $s5.0/(1 + s5.0)$  can be neglected.)

The value of K2 must be selected first to obtain the correct time constant.

$$K2 = \frac{T_{\text{ANG}}}{0.0047} = R15 \text{ in kilohms}$$

If a 0.8 s time constant is desired, for example, then:

$$R15 = K2 = 0.8/0.0047 = 170.2 \text{ k}\Omega$$

A standard value of 169 k $\Omega$  for R15 would be appropriate. Since KR is already fixed at 0.02, the remainder of the required gain must be obtained from K5, K1 and K3. K3 is already set at 3.0 by circuit design consideration. K5 can be set at 2.5 (K5 must be such that voltage on C10  $\leq$  10 V). Then:

$$K5 = 2.5 = \frac{R29 + R30}{R30}$$

Selecting R29 = 50 k $\Omega$ ,  
then R30 = 33.2 k $\Omega$

The value for K1 is then obtained from

$$K1 = \frac{K_{ANG}}{\text{Freq} \times 3.82 \times 10^{-3} \times 0.2 \times K5 \times K2 \times K3 \times 2 \times KR} = \frac{R11}{10.7}$$

As an example, assume the speed wheel frequency is 900 Hz, desired K<sub>ANG</sub> = 400 and K5 = 2.5, K2 = 169, K3 = 3, KR = 0.02.

Therefore,

$$K1 = \frac{400}{900 \times 3.82 \times 10^{-3} \times 0.2 \times 2.5 \times 169 \times 3 \times 2 \times 0.02} = 11.47$$

R11 is then calculated from:

$$\begin{aligned} R11 &= 10.7 \times K1 \\ &= 122.7 \text{ k}\Omega \end{aligned}$$

The selected resistor values should correspond to standard values readily available from suppliers. In this instance a resistor of 124 k $\Omega$  could be used.

Gain K4, around amplifier Q5, is selected to provide a signal of approximately 1.2 V to the level detector for a speed change



corresponding to the desired threshold speed change. The transfer function from the output of Q2 to the output of Q6 is given by:

$$F(s)_{Q2-Q6} = \frac{100/R19}{(1 + s0.01)} \times \frac{2.13 \times s5.17}{(1 + s0.01)(1 + s5.17)}$$

The gain of this transfer function varies as a function of frequency. In the frequency range of interest, the gain can be taken as:

$$\text{Gain } K4 = \frac{178}{R19} \quad \text{V/V}$$

where R19 is in k $\Omega$

Thus, the signal at the input to the level detector will be:

$$V_{\text{detector}} = \text{Speed change in Hz} \times 3.82 \times 10^{-3} \times K5 \times K1 \times K4$$

For the detector to just operate,

$$R19 \text{ (k}\Omega\text{)} = \frac{(\text{Desired } \Delta \text{ speed in Hz}) \times 3.82 \times 10^{-3} \times K5 \times K1 \times 178}{1.2}$$

As an example, for a  $\Delta\omega$  threshold of 0.0015 pu, with 1 pu = 900 Hz, K5 = 2.5 and K1 = 11.47,

$$R19(\text{k}\Omega) = \frac{0.0015 \times 900 \times 19.5}{1.2} = 22 \text{ k}\Omega$$

A value of 22.1 k $\Omega$  for R19 would be suitable.

Limits must be applied to the TSEC output signal and to the output of Q3. Limits are specified by System Planning in per unit of  $E_t$  reference and these values are converted to volts with the help of Figure 2.1. For example, assume that the following limits are specified:

|                       |                                                                  |
|-----------------------|------------------------------------------------------------------|
| Stabilizer signal     | - 0.2 pu                                                         |
| TSEC signal           | - 0.3 pu                                                         |
| Integrator limit (Q3) | - 0.6 pu                                                         |
| $E_t$ limiter         | - High enough to overcome the combined effects of TSEC and Stab. |

The final stabilizer output stage has been provided with +10 V, - 3.3 V limits. These values correspond to 0.2 pu and -0.066 pu when the gain from the stabilizer output signal to the AVR reference voltage summing junction is taken into account. With these limits selected, the individual TSEC,  $E_t$  limiter and stabilizing signal limits can be selected.

If a TSEC signal limit of 0.3 pu is desired, converting this value to volts must take circuit gains into account. The TSEC signal has a gain of 2 at the summing amplifier on the output card. Therefore,

$$0.3 \text{ pu} = \frac{10 \text{ V}}{0.2 \text{ pu}} \times 0.3 \text{ pu} \times \frac{1}{2} = 7.5 \text{ V}$$

Diode D1 in the feedback of Q4 on TSEC 1 must then be a 7.5 V zener for a 0.3 pu limit. Diode D2 is a short to obtain a lower limit of 0.0 pu.

The upper limit on the integrator will be

$$\begin{aligned} 0.6 \text{ pu} &= \frac{10 \text{ V}}{0.2 \text{ pu}} \times 0.6 \text{ pu} \times \frac{1}{2} \times \frac{1}{3} \\ &= 5 \text{ V} \end{aligned}$$

Diode D6 in the feedback of Q3 on TSEC 1 must then be a 5 V zener for a 0.6 pu limit. Diode D5 is a short to obtain a lower limit of 0.0 pu.

Switch SW13, labelled TSEC SIGNAL, is used to place the TSEC circuit in service.

#### 2.3.8 TSEC #2 Card

The voltage regulator signal must be matched to the level detector settings both in magnitude and polarity.

If the regulator signal is positive for a positive field voltage, jumper SL5 is inserted and amplifier Q1 is removed. If the regulator signal is negative for a positive field voltage, SL5 is opened and Q1 is installed.

Components R1, R2, R3, C1 and C2 on this card provide filtering and gain reduction to match the AVR output signal to the level detector operating threshold. R2 is fixed at 10 k $\Omega$  and R1 is obtained from

$$R1 = (2 V_{op} - 10) \text{ k}\Omega$$

where  $V_{op}$  is the desired magnitude of AVR output signal which will enable the TSEC circuit.

For example, in the Bruce 'A' type exciters, an AVR signal of -10 V will produce positive ceiling voltage. Allowing for some margin, a value of -8.5 V would be selected for  $V_{op}$ .

$$R1 = 2 \times 8.5 - 10 = 7 \text{ k}\Omega$$

A standard value of 6.98 k $\Omega$  would be used. Components C1 and R3 would only be used in rare instances where the AVR signal is exceptionally noisy. Normally C1 is not installed and R3 is a jumper.

Switch SW14, labelled AVR SIGNAL, on this card must be in the ON position for the voltage regulator signal to be connected to the level detector.

Link SL6 is normally installed to connect pin 6 of Q3 to pins 9 and 10 of Q3. In some situations, if the AVR signal is not used in the logic, link SL6 ties pins 9 and 10 to the +15 V bus.

The terminal voltage signal for this card is obtained from the  $E_t$  limiter card. In the  $\Delta\omega$  stabilizer, this signal proportional to  $E_t$  is:

$$E_t' = -53.6 \times \frac{\text{Rated Terminal Voltage (kV)}}{\text{PT ratio}}$$

When  $E_t'$  is negative, Q12 is installed and link SL7 is not installed.

The change in magnitude of the signal on pin 10 of card TSEC 2, or at the output of Q12 is:

$$\Delta E_t' = \Delta E_t \text{ (pu)} \times 53.6 \times \frac{\text{Rated } E_t \text{ (kV)}}{\text{PT ratio}} \text{ V}$$

For the  $\Delta E_t$  detector to operate for a given change in  $E_t$ , the signal out of Q7 must be  $\geq 6.2$  V.

The gain of Q7 must then be

$$G_{in} = \frac{6.2 \times \text{PT Ratio}}{\Delta E_t (\text{pu}) \times 53.6 \times \text{Rated } E_t (\text{kV})} \text{ V/V}$$

where  $\Delta E_t$  is the desired threshold.

Due to the filtering around Q7, the gain varies with frequency. Bench tests have demonstrated that for the purposes of a step change in  $E_t$  the gain can be approximated by

$$\text{Gain} = 0.058 \times R28 \text{ (k}\Omega\text{)}$$

The value of R28 is then obtained from:

$$\begin{aligned} R28 \text{ (k}\Omega\text{)} &\approx \frac{6.2 \times \text{PT Ratio}}{\Delta E_t (\text{pu}) \times 53.6 \times 0.058 \times \text{Rated } E_t (\text{kV})} \\ &\approx \frac{2.0 \times \text{PT Ratio}}{\Delta E_t (\text{pu}) \times \text{Rated } E_t (\text{kV})} \text{ k}\Omega \end{aligned}$$

As an example, assume that the desired threshold is  $\Delta E_t = 0.05$  pu, 1 pu = 18.5 kV and the PT ratio = 150/1.

$$R28 = \frac{2.0 \times 150}{0.05 \times 18.5} = 324 \text{ k}\Omega$$

It may be necessary to vary R28 slightly to obtain the correct threshold during initial bench calibration.

Timer #1 will seal-in the simultaneous operation of the AVR and  $\Delta E_t$  level detectors for a selected period of time to give the  $\Delta \omega$  detector a chance to operate and satisfy all the logic conditions. The seal-in time is determined by R13 and C5 from the equation below:

$$\text{Seal-in time} = 1.1 \times R13 \text{ (k}\Omega\text{)} \times C5 \text{ (}\mu\text{f)} \times 10^{-3} \text{ s}$$

A seal-in time of 0.25 s should be adequate in most cases. C5 can be set at 0.1  $\mu$ f. Then,

$$R13 \text{ (k}\Omega\text{)} = \frac{0.25}{1.1 \times 0.1 \times 10^{-3}} = 2.27 \times 10^3 \text{ k}\Omega$$

$$= 2.27 \text{ M}\Omega$$

use R13 = 2.4 M $\Omega$

Timer #2 is used to override the TSEC logic and cause relay RE-5 on TSEC 1 to drop out a fixed time delay after initiation. Resistor R14 is selected for the desired time from:

$$R14 \text{ (k}\Omega\text{)} = \frac{\text{Time delay}}{1.1 \times C8 \text{ (}\mu\text{f)} \times 10^{-3}}$$

A time delay of 3 s will be appropriate in most cases and with C8 = 2.2  $\mu$ f,

$$R14 = \frac{3}{1.1 \times 2.2 \times 10^{-3}} = 1.24 \times 10^3 \text{ k}\Omega$$

A standard value of 1.5 M $\Omega$  for R14 would be suitable.

### 2.3.9 Disturbance Generator (Test 1)

The disturbance generator card is provided to facilitate periodic testing of the stabilizer. Small step disturbances can be introduced by operating the push button on the card. The magnitude and polarity of the disturbance are controlled by potentiometer P1-12 and switch S12. Under normal conditions P1-12 is set at zero and S12 to the OFF position. When it is necessary to introduce a disturbance S12 is set for the desired polarity and, as the push button is operated repeatedly, P1-12 is gradually increased until a disturbance of the required magnitude is obtained. Upon completion of the tests, P1-12 must be reset to zero and switch S12 to OFF.

The maximum disturbance which can be introduced using the test card when the unit is at rated voltage is a 5% change in terminal voltage.

TABLE 2-1

IN-SERVICE SETTINGS OF  $\Delta\omega$  STABILIZERS AT BRUCE 'A' NGS

|                          |                    |
|--------------------------|--------------------|
| P1 on $\Delta\omega$ Amp | 0.25/1             |
| P1 on Phase Lead         | 0.0/1              |
| P2 on Phase Lead         | 1.0/1              |
| P1-7 on Limiter Card     | - to be determined |



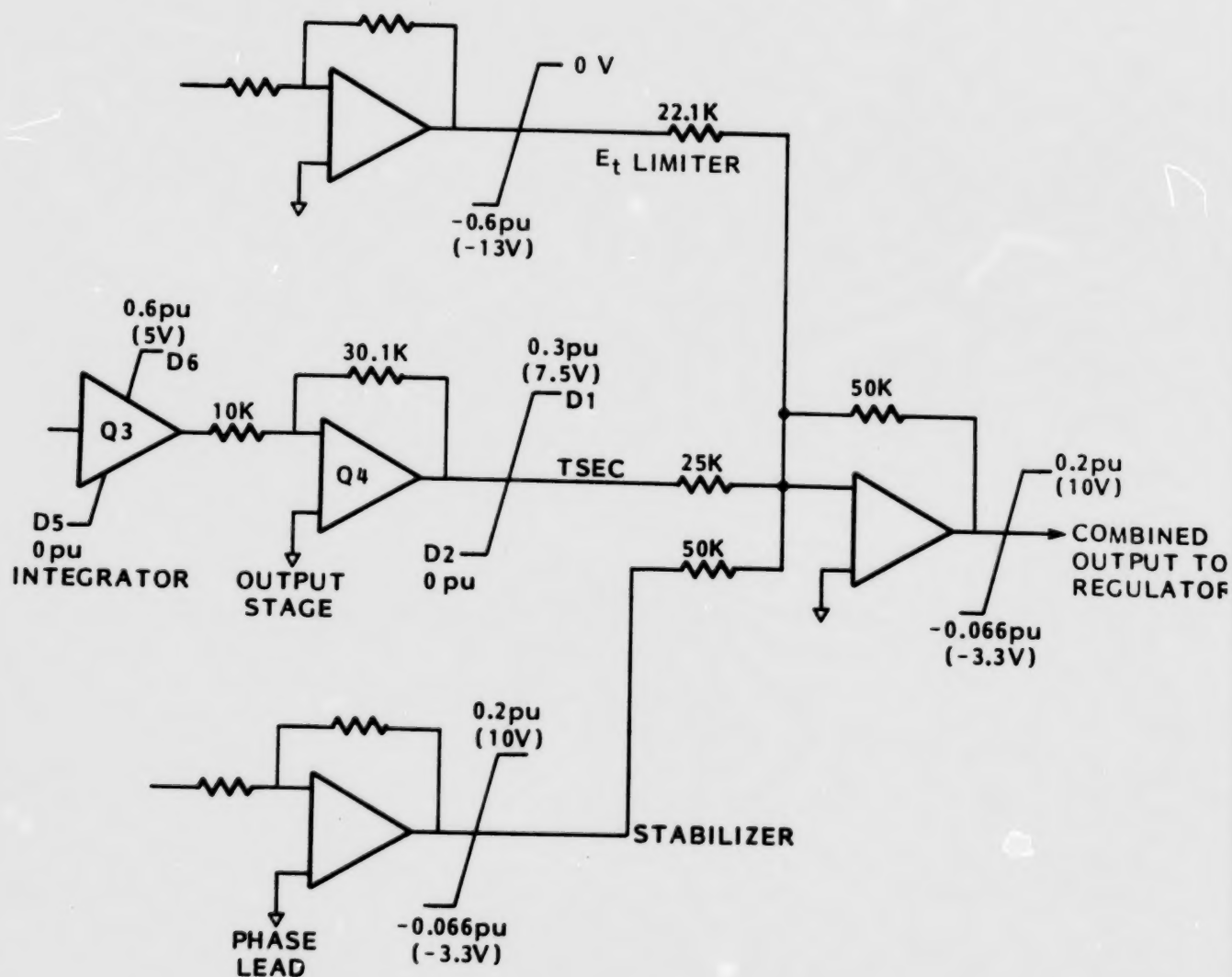


FIGURE 2.1  
LIMITS ON  $E_t$  LIMITER, TSEC AND STABILIZER SIGNALS

### SECTION 3

#### MODELLING AND BLOCK DIAGRAM REPRESENTATION

A detailed transfer function block diagram of the  $\Delta\omega$  stabilizer is provided in Figure 3-1. This shows a representation that can be used with any stabilizer settings. For most studies this degree of complexity is not required and a simpler representation is shown in Figure 3-2. For the in-service stabilizer settings, frequency response plots for the actual and the reduced models are shown in the curves of Figure 3-3. The reduced model is valid for frequencies up to about 2 Hz.

The TSEC circuit can be modelled using the simplified representation of Figure 3-4. All gains and time constants are as per in-service settings.

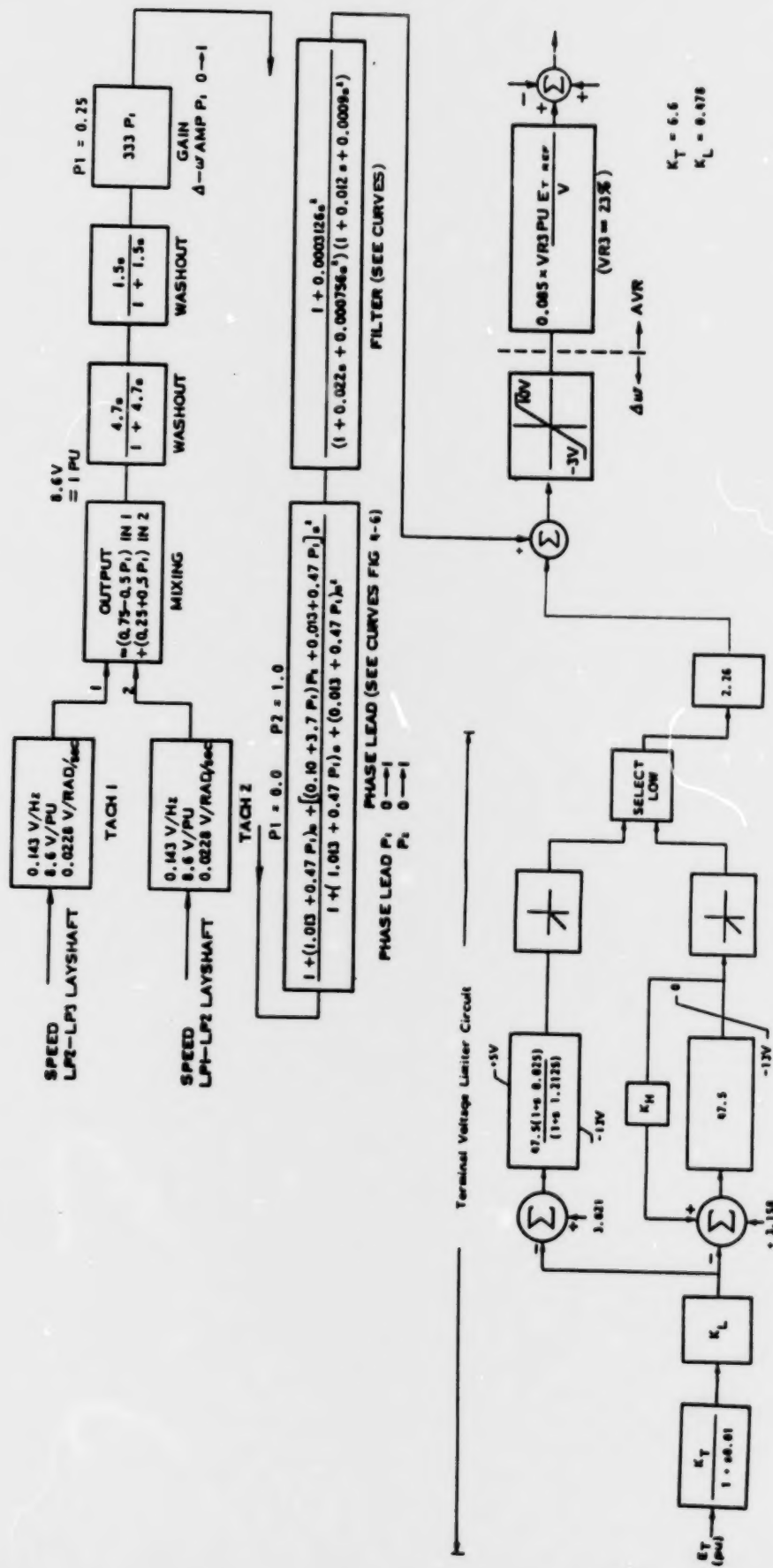
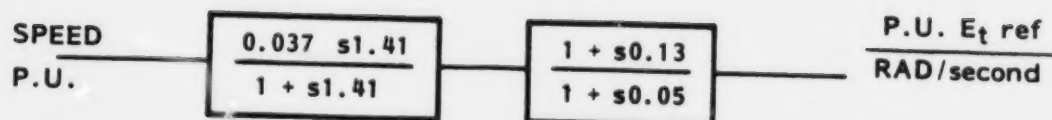


FIGURE 3-1  
BRUCE "A" GS - DELTA-OMEGA STABILIZER  
TRANSFER FUNCTION BLOCK DIAGRAM  
(EXCLUDING TSEC FUNCTION)  
REVISED AUG 1986



NOTE:- TORSIONAL FILTER NEGLECTED  
 - PHASE LEAD REDUCED TO SINGLE ORDER  
 -  $E_t$  LIMITER AND TSEC OMITTED

FIGURE 3-2  
 REDUCED BLOCK DIAGRAM OF BRUCE A  $\Delta w$   
 STABILIZER WITH IN-SERVICE SETTINGS

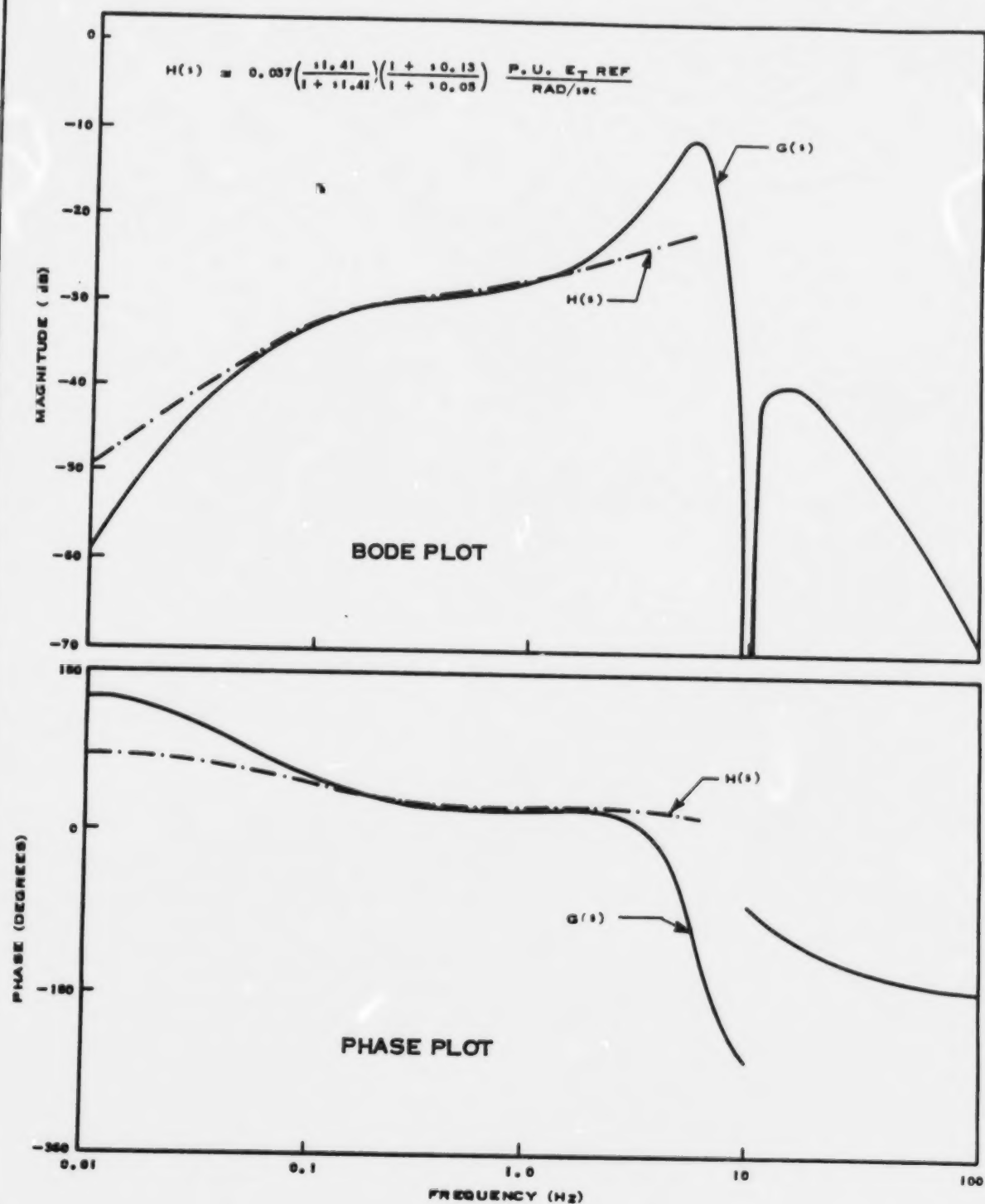
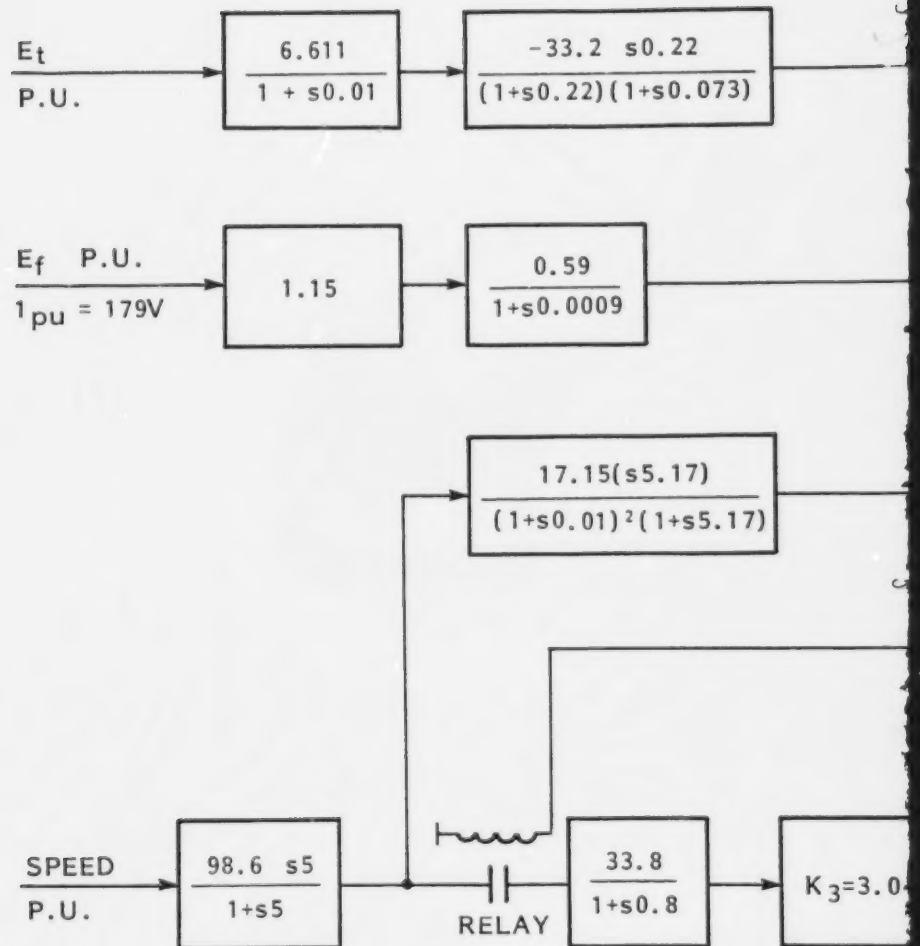


FIGURE 3-3  
 FREQUENCY RESPONSE CHARACTERISTICS OF COMPLETE STABILIZER  
 (FIG. 3-1) AND SIMPLIFIED MODEL - BRUCE "A" GS  
 (REVISED SEPT. 1984)





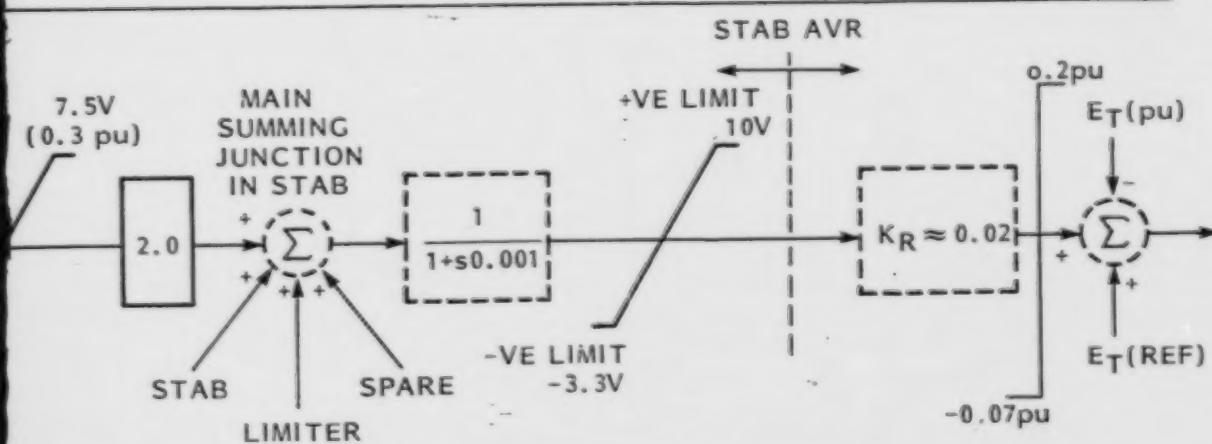
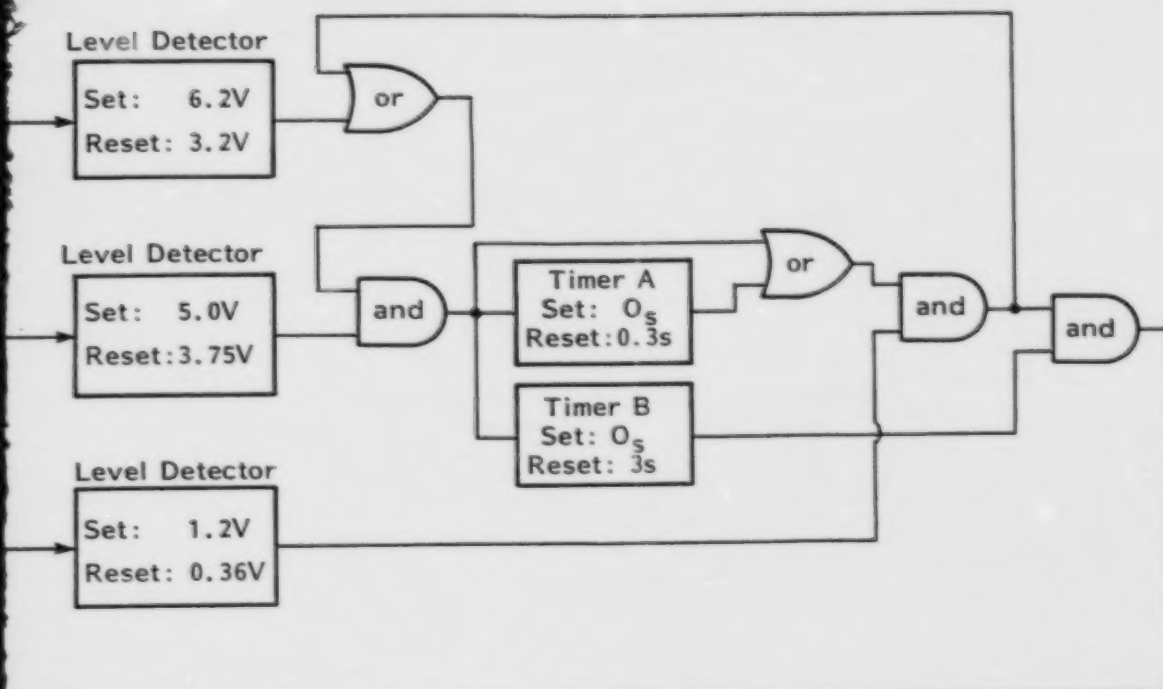


FIGURE 3-4  
REDUCED BLOCK DIAGRAM  
OF TSEC CIRCUIT  
BRUCE A -  $\Delta_w$  STABILIZER  
SEPT. 1984

## SECTION 4

### DETAILED CIRCUIT DESCRIPTIONS

#### 4.0 GENERAL

In the title of the subsection the full name of the card is given followed, in capital letters, by the designation to be found on the faceplate of the card and, in brackets, the printed circuit card designation engraved on the PC board. The card designation such as CBB1 or  $\Delta P\omega 14$  has no special significance except to act as an identification mark on the PC board; the number at the end of the designation is the card number. Resistor values shown on the schematics are nominal values. The installed values, shown by the colour coding, are given in the parts list of Section 6.

#### 4.1 Speed Signal Generating Circuit

The Bruce 'A' GS turboalternator sets have four pole generators and hence they rotate at 1800 rpm when synchronized to the system.

The speed, as measured at any point along the turbine-generator shaft, consists of the main rotational speed (1800 rpm) with any changes in speed as the machine interacts with the power system superimposed. In addition, when perturbed, small oscillatory components of speed corresponding to the torsional modes of oscillation of the multi-mass rotor may be evident. To measure the speed changes of the machine against the system with a minimum of these torsional components, two speed sensing locations were used. By using these two signals, the node of the first torsional (Figure 1-2) can be simulated. Between LP1 and LP2 and between LP2 and LP3 are located short lay shafts. Each lay shaft has 15 slots milled in it and two electromagnetic pickups located 180° apart sense these surface discontinuities as the shaft rotates.

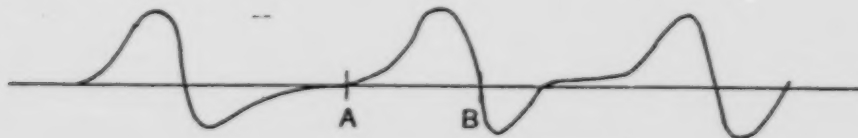
The speed pickups are electromagnetic sensors model 3010AN manufactured by Electro Corporation, Sarasota, Florida. The sensing head of the pickup is located at approximately 1.3 mm (0.050 inch) from the toothed wheel or the milled shaft. As a slot passes by a pickup, a pulse of 10-25 V peak amplitude is generated and, by means of doubly shielded cable, fed to the stabilizer electronics.

#### 4.2 Speed Signal Input - INPUT - (CBB1) (2 per stabilizer) (Schematic: Figure 4-1)

The speed signal input card is a dual input channel circuit to accommodate either single or twin speed pickup arrangements. The speed signal appears on edge connector pin (ECP) 9 for a single input, or ECP9 and ECP10 for dual inputs. Only one channel operation will be described here.

The speed signal is filtered and scaled down by a factor of 2 by R1, C1 and R2 and applied through R5 to pin 4 of a LM311J voltage comparator. The voltage comparator output is 4.5 V dc whenever the signal on pin 4 is less than that on pin 3. The output voltage is fed back to pin 3 through a diode and a 3.3 k $\Omega$  resistor, establishing approximately a 2.25 V dc reference on pin 3. Whenever the signal on ECP9(TP1-1) reaches a value of +4.5 V, the reference on pin 3 is exceeded and the output of the comparator goes to zero (comparator operates). As the speed signal crosses zero and goes negative, the comparator output returns to +4.5 V dc (resets). A square wave is thus generated at the output of the comparator, in step with the speed signal. This squaring circuit eliminates any inter-pulse noise due to shaft dents and interference picked up in the leads and provides a signal which is locked to the zero crossings of the speed signal. Amplitude modulation of the speed signal caused by shaft runout is eliminated.

**CAUTION:** For the proper functioning of the stabilizer it is important that the polarity of the speed signal be selected correctly. As mentioned above, the comparators "operate" at a 4.5 V level and "reset" when the speed signal goes through zero. Normally the speed signal obtained from the magnetic sensors is not a clean sine wave, but rather it has the form shown below:



It will be noted that the zero crossing at A is not as well defined as that at B. It is therefore necessary to connect the polarity of the speed signal such that

the zero crossing at B causes the "reset" and the positive going slope following the flat portion causes the "operate" when it exceeds +4.5 V. If the polarity is reversed a very large noise component will be present in later stages of the speed signal path. This noise will generally consist of a large speed signal excursion once per shaft revolution.

The outputs of the two level detectors are summed through diodes D7 and D8 and applied to the input of a monostable (SN74121N) with a pulse width adjustable by means of potentiometer P1 on the card. The pulse width, in ms, is then:

$$\text{Pulse width} = \frac{60 \times 10^3}{\text{Shaft rpm} \times \text{No of slots} \times \text{No of pickups} \times 2}$$

If the pickups are not exactly 180° apart, the space between alternate pulses at TP1 of the tach card will be  $0.556 \text{ ms} + \Delta t$  and  $0.556 - \Delta t$ . With the pickups 180° apart  $\Delta t = 0$ . Tests have shown that the electrical "noise" created by having the pickups not exactly 180° apart is not excessive, and circumferential adjustment will not normally be required.

The supply for all of the input card circuits comes from a +5 V regulator mounted on this card. The regulator is in turn supplied from the +15 V stabilizer supply.

In this system two input cards are used, each of which feeds a separate tach card.

#### 4.3 Tach-TACH-(CBB2) (2 per stabilizer) (Schematic: Figure 4-2)

The complementary square waves from the speed signal input card are applied to edge connector pin ECP5 and ECP6 of the tach card. The square waves are used in a push-pull fashion to drive a saturable transformer model 175-991-007 (1.0 kHz), manufactured by Air-Pax and available from Leonard Electric in Toronto. At each flux reversal of the transformer core, an equal voltage-time area pulse is produced. The peak amplitude of the pulse is determined by the reference voltage established by R5 and D1, and 11.7 V zener diode. The output pulse is -12.5 V in amplitude and 240  $\mu\text{s}$  in width. Pulses are produced at twice the frequency of the square waves from the input card. These equal area pulses are of alternate polarity and a rectifier arrangement, D2 and D3, is used to produce a train of unipolar pulses at twice the frequency of the speed signal.

A high speed operational amplifier (Motorola MC741SCP1) is employed for isolation, linearization and gain reduction of the pulses. The pulses are then filtered in an RC ladder network to produce a dc level proportional to speed. This signal is on ECP9.

A direct output from the isolating amplifier is connected to ECP21 for use in the Transient Stability Excitation Control (TSEC) cards.

The transfer ratio of the tach card from ECP5 and ECP6 to ECP9 is  $3.82 \times 10^{-3}$  V/Hz.

Two tach circuits are employed, one for each of the two speed wheels and associated input cards.

#### 4.4 Missing Pulse Card - MISSING PULSE - (CBB9) (Schematic: Figure 4-3)

This card actually performs the dual role of (a) adding the speed signals from the two pickup wheels and (b) detecting loss of input signal from any pickup.

The two tach card outputs go to two amplifiers on the missing pulse card. Outputs of these two amplifiers (TP1 and TP2) are summed in a third amplifier (output at TP3). By turning pot P1, the ratio of the signals from the two tach circuits is changed, although the amplitude at TP3 remains relatively unchanged. With  $P_1 = 50\%$  the ratio of signal from the two speed wheels is unity. The output at TP3 as a function of P1 setting may be defined approximately as follows:

$$W(TP3) = (0.75 - 0.5 P_1)W_1 + (0.25 + 0.5 P_1)W_2$$

P<sub>1</sub> should not be adjusted with the stabilizer in service

Provision has been made to allow the replacement of P<sub>1</sub> with fixed resistors after initial system set up.

Signal fail detection consists of:

1. Detection of loss of signal (one pickup or both) from each speed wheel location.
2. Detection of signal out of range (positive or negative) after summing.



Dual zero crossing level detectors (LM319) are used for signal fail detection. Normally all four outputs are high. Any one output going low will drive the logic (TP4) low and initiate the signal removal, etc.

A fixed fraction of the  $\pm 8$  V outputs of each of the first two amplifiers is compared to a  $-5$  V reference level. The detector operates and its output goes low for an output of either amplifier more positive than  $-6$  V.

Output of summing amplifier Q3 (TP3) is supervised by a window level detector. The detector output is low unless the summing amp output is within set limits ( $+6.5$  to  $+9.5$  V). A positive  $5$  V reference (TP6) is used for this comparison.

The mixed signal, with amplitude proportional to speed at the node of the first torsional mode now goes to the  $\Delta$ -W amplifier card. Output of the level detector (TP4) goes to the output card, where it acts to trip the stabilizer, alarm and change to the alternate voltage regulator for a signal outside limits at any of the three amplifier outputs.

#### 4.5 Delta-Omega Amp Card - $\Delta\omega$ AMP - (CBB3) (Schematic: Figure 4-4)

The combination of the resistors of the ladder network (from the previous card) and the capacitor C3 of this card, provide a high pass or washout function with a  $4.7$  s time constant. The dc component of the speed signal is blocked and only speed changes are amplified in the first stage (TP1). The second stage consists of another washout (with  $1.5$  s time constant) and further amplification (TP2). The potentiometer P1 sets the overall gain of the stabilizer. Trimpot P2 allows amplifier offset adjustment. The second stage output then goes to the phase lead card and the third stage of the Delta-Omega amplifier card. The third stage combines the second stage output with the output of the phase lead circuit.

#### 4.6 Phase Lead Card - PHASE LEAD - (CBB6) (Schematic: Figure 4-5)

The function of this card is to add an acceleration or phase lead component to the speed signal. P1 sets the time constant of the phase lead component and P2 sets the phase lead gain.

The transfer function between TP2 of the Delta-Omega Amp Card and TP1 of the filter card including the phase lead component, can be represented by

$$F(s) = \frac{1 + T1 \cdot s + (T2 + T1 - 1) \cdot s^2}{1 + T1 \cdot s + (T1 - 1) \cdot s^2}$$

where  $T1 = 1.013 + 0.47 \cdot P1$

$T2 = (0.10 + 3.7 P1) \cdot P2$

$P1$  and  $P2$  vary between 0 and 1.0.

Curves of this characteristic are shown in Figure 4-6.

#### 4.7 Filter Card - FILTER - (CBB4) (Schematic: Figure 4-7)

This circuit is designed to eliminate any components of the speed signal which correspond to torsional oscillations of the turbine generator shaft. A frequency response of the filter is shown in Figure 4-8. The filter provides a deep notch for signals at a frequency corresponding to the first torsional mode (9 Hz), and not less than 20 dB attenuation for higher frequencies. The filter is designed to have a minimal effect at the frequencies for which stabilization is desired (-0.5 - 1 Hz).

Components on this card are chosen in a specific manner. If it is necessary to replace any component, the entire frequency response curve (Figure 4-8) should be carefully checked. The notch is adjustable over a narrow range by means of a potentiometer  $P1$ . This is set to the frequency of the first torsional mode and should not be altered. The transfer function for this circuit is:

$$F(s) = \frac{1 + 0.0003126s^2}{(1 + 0.22s + 0.000756s^2)(1 + 0.012s + 0.0009s^2)}$$

If the circuit malfunctions, it should be returned to the Ontario Hydro research lab for repair. Field repair should not be attempted.

Test points TP11 and TP12 are provided for monitoring. Trimpots P8 and P9 allow dc offset adjustment.



#### 4.8 Terminal Voltage Limiter - LIMITER - ( $\Delta P_{\omega 7C}$ ) (Schematic: Figure 4-9)

With the installation of Transient Stability Excitation Control circuits it was necessary to modify the terminal voltage limiter to remove the heavy filtering that was originally present in the feedback of the comparator amplifier. This was done to prevent any possible interaction between the limiter circuit and shaft torsional components. The new circuit, shown in Figure 4-9 uses the amplifier as a comparator with hysteresis. The overall operation of the circuit is described below with the help of Figure 4-10.

The terminal voltage limited circuit produces a negative output voltage whenever the three-phase input voltage goes above a certain value set by P1-7 and one of two fixed dc references.

The three-phase terminal voltage from the generator PTs is stepped down from a nominal 120 Vac phase-phase. The step down transformers are single-phase transformers rated 115/15 V and connected Y: $\Delta$  to increase the line-to-line rating to 200 V maximum. The secondary voltage is rectified by diodes D1 to D6 and filtered by R1 and C3. A portion of this dc voltage, determined by the setting of P1-7, is fed to buffer amplifier Q1. The output of Q1 is fed to two comparators, one formed by Q2 and the other formed Q3.

When the dc voltage proportional to  $E_t$  becomes greater than the dc reference voltage of Q2, fixed by  $-15 \cdot R_2 / R_6 = -3.158$ , the voltage difference is amplified by the high gain of Q2, 47.5, causing the output at pin 6 of Q2 to go negative. R4 provides some hysteresis to avoid hunting of the terminal voltage when working against the limit.

When the same dc voltage proportional to  $E_t$  becomes greater than the dc reference voltage of Q3, fixed by  $R_{17}(-15 \cdot R_{15} / R_{17} = -3.021)$ , the voltage difference is amplified by the gain of Q3 and filtered by the feedback circuit to provide a slow response. Diode D10 forces the slow limiter to start from a +5 V output, thus delaying its action by approximately 1 second.

At Bruce 'A' the fast acting limiter is normally set to limit at 1.13 per unit and the slow limiter starts at 1.08 per unit. Diodes D8 and D13 connect the two circuits together and automatically select the most negative output.

Amplifier Q4 provides an optional inverting stage when this card is used in  $\Delta \omega$  stabilizers.

A dc signal proportional to  $E_t$ , but not affected by P1-7, is available on ECP 10 and 11 for use in the TSEC circuit and the dynamic test facilities.

Three test points are provided:

- TP1-7: Output of Slow limiter
- TP2-7: Output of Fast limiter
- TP3-7: Combined output.

#### 4.9 Output Card - OUTPUT - (CBB5) (Schematic: Figure 4-11)

Output of the signals from the filter card, the TSEC circuit, the disturbance generator and the terminal voltage limiter are combined in a final unity gain amplifier stage. An additional input (TP5) allows the introduction of test signals. A zener diode and diode combination limits the signal output in the negative direction.

The stabilizer is connected to the AVR through relay R1 and a signal switch. When the signal is turned off both signal and common of the stabilizer are isolated from the voltage regulator. The AVR input is shorted if either the relay R1 is dropped out or the signal switch is open, as shown in Figure 4-11.

A separate circuit, isolated from the rest of the stabilizer electronics, is used for some of the switching. If the breaker pallet is open, relay R1 drops out, the stabilizer is disconnected and the alarm function is blocked. When the pallet closes, R3 picks up and removes alarm signal blocking. If a power supply failure signal, or missing pulse alarm signal is being received, the stabilizer is not placed in service. Relay R2 is dropped out, preventing R1 pickup and completing the alarm transfer circuit. Turning the signal switch off with the breaker pallet closed also initiates alarm/transfer. If the stabilizer input pulsing is satisfactory and the power supply is within limits, relay R2 picks up allowing R1 to pick up through the time delay circuit (~13 s, as shown in Figure 4-11).

Under normal condition R2 would be picked up and the breaker pallet would initiate R1 operation, connecting the stabilizer. For signal failure, or power supply failure, relay R2 drops out immediately. This drops out R1 and resets the timer by discharging C6.

At Bruce 'A' GS, operation of the alarm function will disconnect the stabilizer and transfer control from the A Voltage Regulator

channel to the alternate B regulator. The B regulator is equipped with a  $\Delta P_w$  stabilizer.

#### 4.10 +15 V Power Supply - POWER SUPPLY - (CBB8) (Schematics: Figure 4-12 and 4-13)

The power supply chosen for these stabilizers is an R.O. Associates Model 514 dual 15 V supply, modified to meet the stabilizer requirements.

Capacitors C7 and C8 (R.O. Associates drawing No C1197 Rev K, Figure 4-13) had been added by the manufacturer to allow stability with a large range of components. Unfortunately, they seriously limit the high frequency recovery for load changes. These two capacitors have been removed for the Bruce 'A' stabilizers.

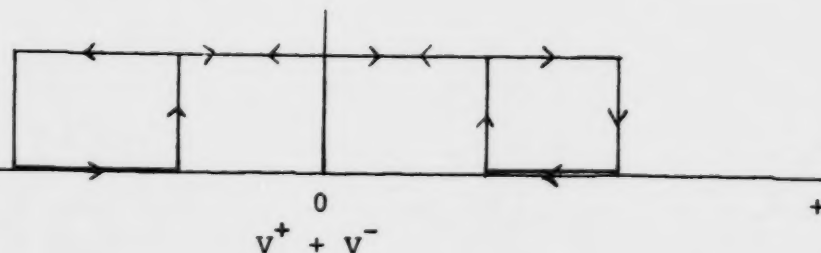
One of the requirements of the stabilizer is that it remain in service and function normally for faults of up to 240 ms duration on the high side of the unit step-up transformer. For this condition the generator terminal voltage from which input to the supply is derived will drop to about 50% of normal.

In order to ensure that the power supply continues providing  $\pm 15$  V to the electronics for this 240 ms interval, it was necessary to boost the power supply filter capacitors as shown in Figure 4-12. (A 10 000  $\mu$ F capacitor was added in parallel with R.O.'s C1 and 1000  $\mu$ F capacitor was added in parallel with R.O.'s C2). A resistor-diode combination was employed to limit the charging rate of these capacitors.

The components on CBB8 (on which the R.O. supply is mounted) constitute the power supply failure detection circuitry. With the +15 and -15 supplies at their nominal levels, the output of Q2 is high and relay R1 is picked up. If one supply level deviates, the output of Q2 will go low and the relay will drop out. This characteristic including built-in hysteresis is shown below:

$$Q_2 = +12 R_1 \text{ PU}$$

$$Q_2 = 0 R_1 \text{ DO}$$



If the positive supply level drops below +10, the relay will drop out (Q2 low) regardless of the negative supply level.

Relay R1 is not used with the  $\Delta\omega$  stabilizer.

In this power supply, the negative voltage normally tracks positive supply voltage changes.

4.11 Test #1 - TEST - ( $\Delta P\omega$  12)  
(Schematic: Figure 4-14)

Test #1 card is used to introduce step disturbances to the voltage regulator through the stabilizer input.

Switch S3 selects either the positive or negative bus voltage reduced through a variable resistive voltage divider formed of R1 or R3 and P1-12. A push button on the front of the card (or via the front pin jacks) connects this voltage through R3 to the summing amplifier on the output card. The dc voltage that appears at TP1 of the output card when the push button is pressed and S3 is in the POS or NEG positions is:

$$\begin{aligned} V_{TP1} &= (+15) \left( \frac{10 \times P1-12}{30} \right) \left( \frac{47}{2 \times 47} \right) \\ &= +2.5 \times P1-12 \end{aligned}$$

where  $P1-12 = 0 \rightarrow 1.0$

The maximum disturbance which can be introduced is 5% of rated terminal voltage assuming a voltage regulator input gain KR of 0.02.

4.12 Isolator Card - ISO-1 - (ISO-1)  
(Schematic: Drawing 32336 - Figure 4-15)

Isolator card ISO-1 consists of a small dc/dc converter providing an isolated dc supply and two operational amplifiers to isolate the stabilizer output signal by means of high value resistors. The stabilizer signal is connected in a differential mode to the first amplifier, type OP07 with the stabilizer power supply common forming the low side of the signal. The main power supply common and the converter common should not be tied together. The output to a suitable recorder is through a 741 amplifier and a 5 k $\Omega$  resistor to protect the circuit against accidental backfeeds on the test point marked  $\Delta\omega$ . The overall gain through the circuit is x1 but the instrument connected to TP- $\Delta\omega$  must have an input impedance greater than 100 k $\Omega$  to avoid loading effects.

Note that COM marked with a 1 on the schematic is the stabilizer main power supply common whereas the COM marked with a 2 is the common of the isolated power supply.

#### 4.13 TSEC #1 - ( $\Delta P_{\omega 13-1}$ , TSEC1-1) (Schematic: Figure 4-16)

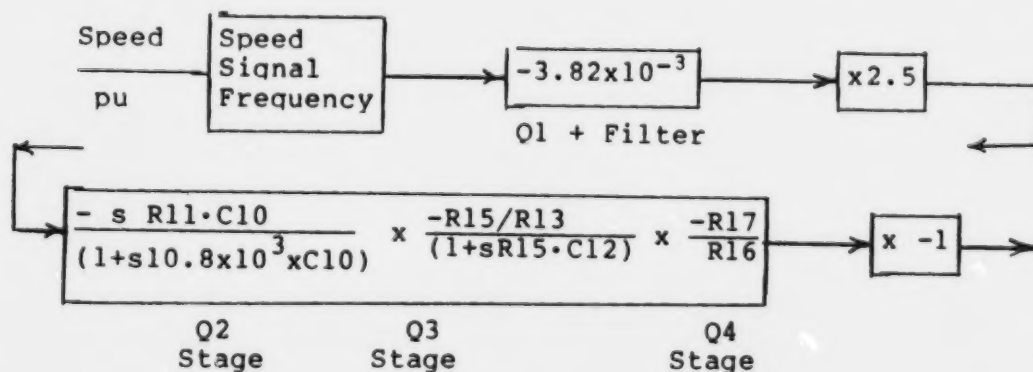
The input to this card on ECP10 are the pulses from the output of isolation amplifier Q7 on the Tach card. Amplifier Q1 provides isolation for the RC ladder filter located on the TSEC1-1 card. The output of the ladder filter is:

$$V_{out} = 3.82 \times 10^{-3} \times (\text{speed signal frequency in Hz}) \text{ V dc}$$

Amplifier Q7, connected as a follower with gain, provides isolation between the ladder filter and the rest of the circuit. The dc signal from Q7 is removed by capacitor C10 so that only changes in speed will be integrated and amplified in later stages. When relay RE-5, driven by the logic on the TSEC-2 card operates, the change-in-speed signal from Q2 feeds through to an integrator or low pass filter, formed by Q3, C12, R15 and R13. Gain and signal limiting is also provided in that stage. A further gain of 3 and limiting to +7.5 V, -0.5 V are provided by Q4 and diodes D1 and D2. Potentiometer P3 is used to null the output of Q2 with a steady state speed signal on ECP10.

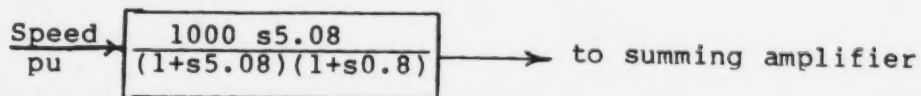
The output of Q4 is inverted by amplifier Q8 and fed through SW13 (labelled TSEC SIGNAL on the front of the card), to the summing amplifier on the output card, CBB9. When RE-5 is de-energized, resistor R12 ensures that the output of Q4 will return to zero with the time constant determined by R15, C12.

The overall transfer function, from the speed input signal to the output on ECP9 is:





Using component values and the speed signal frequency for Bruce 'A' NGS, the transfer function becomes:



The above transfer function can be further simplified if, for frequencies between 0.5 to 3 Hz, the relationship:

$$s5.08 \gg 1$$

is used. Then, the transfer function reduces to

$$T(s) = \frac{10\,000}{(1+s0.8)}$$

If the gain of 2 in the output card and the gain of 0.02 in the voltage regulator input are taken into account, the overall transfer function, from speed input to pu AVR reference voltage is:

$$T'(s) = \frac{400}{(1+s0.8)}$$

The output of Q2, which represents the change in speed signal, also feeds a two stage amplifying and washout circuit formed by Q5 and Q6 and associated components. The output of Q6 is measured by a level detector on TSEC#2 card. The transfer function realized by Q5 and Q6 is:

$$\frac{TP2-13}{TPI-13} = F(s) = \frac{R21/R19}{1+sR21 \cdot C14} \times \frac{s R24 \cdot C15}{(1+sR22 \cdot C15)(1+sR24 \cdot C16)}$$

and again, using Bruce 'A' component values,

$$F(s) = \frac{9.5 s5.23}{(1+s0.01)(1+s5.23)(1+s0.01)}$$

The use of highly stable OP07 type operational amplifiers ensures that under normal conditions there will be no output from the TSEC circuit.



4.14 TSEC-2 ( $\Delta P_w$  14 A, TSEC 2A)  
(Schematic: Figure 4-17)

This card contains three level detectors and some associated logic to drive relay RE-5 on the TSEC-1 card whenever three specific conditions are satisfied. The conditions are:

- a) Voltage regulator output is at ceiling.
- b) Speed has increased by a set value.
- c) Terminal voltage has dropped by a set value.

When the logic operates it also operates a second relay, RE-6 which can be used to annunciate and lights a LED on the front of the card.

The voltage regulator signal comes onto the card on ECP11 and if SW14 (labelled AVR SIGNAL on the front of the card) is closed, goes through a voltage divider and filter formed by R1, R2, R3, C1 and C2. These components are selected as per Section 2.3.8 to fit the voltage level of the particular regulator to the level detector on this card. Amplifier Q1 and soldered link SL-5 allow the matching of a positive or negative going regulator signal to the level detector. If the regulator signal is positive for a positive field voltage, Q1 is not installed and SL-5 is IN. If the opposite is the case, Q1 is IN and SL-5 OUT.

The change-in-speed signal comes onto the card at ECP8 and goes to a level detector directly.

The terminal voltage signal is obtained from the voltage limiter card CBB7 and comes onto the card on ECP10. It goes through an optional inverting stage formed by Q12 and then through a wash-out filter formed with Q7, with a transfer function given by:

$$\begin{aligned} \frac{\text{Output of Q7 (s)}}{\text{ECP10}} &= \frac{+sC10 \cdot R28}{(1+sC10 \cdot R27)(1+sC11 \cdot R28)} \\ &= \frac{+33.2 \text{ s}0.22}{(1+s0.22)(1+s0.073)} \end{aligned}$$

All the comparators are designed the same way and only differ in their resistor values, setting the pickup and dropout voltage levels. As an example, the circuit around Q2 will be used.

When the regulator voltage signal at pin 3 of Q2 is below the reference voltage on pin 2, the output at pin 7 is high. The reference voltage V3 at pin 2 is:

$$V_{2H} = \frac{R_9(V^+(R_{10}+R_{11}+R_8) - V_D \cdot R_8)}{R_7(R_9+R_{10}+R_{11}) + R_9(R_{10}+R_{11})}$$

$V^+$  = positive supply

$V_D$  = diode drop

Since  $R_{11}$  is much smaller than the other resistors and  $V_D$  is small, the above expression simplifies to:

$$V_{3H} = V^+ \left(1 + \frac{1/R_9}{1/R_8 + 1/R_{10}}\right)^{-1}$$

If the signal on pin 3 of Q2 rises above  $V_{3H}$ , then the output of Q2 goes low. Diode D3 becomes reversed biased and  $R_{10}$  no longer has an effect; so, the voltage on pin 3 becomes:

$$V_{3L} = V^+ \frac{R_9}{R_8+R_4}$$

This creates hysteresis around the switching level and Q2 picks up at  $V_{3H}$  and drops out at  $V_{3L}$ . Diodes D1 and D2 limit the input signals to between common and the positive supply. In Table 4.14.1 are listed the switching threshold levels of the three comparators.

TABLE 4.14.1  
SWITCHING THRESHOLDS OF TSEC-2 COMPARATORS

| Comparator | Pick Up<br>(pin 7 high to low) | Drop-Out<br>(pin 7 low to high) |
|------------|--------------------------------|---------------------------------|
| Q2         | 5 V dc                         | 3.75 V dc                       |
| Q5         | 1.2                            | 0.36                            |
| Q7         | 6.2                            | 3.2                             |

The logic levels of the three comparators are processed by NAND gates and two timers to activate relay RE-6 and the LED on the same card and relay RE-5 on card TSEC-1. The operation of the logic and timers is described below.

Whenever Q2 and Q8 comparators are both operated (outputs low), Q3 pin 8 goes low and as it goes low it sets the two timers to a high output on pin 3. Timer #1, with a seal-in time of 300 ms applies a high signal to pin 9 input of Q4. If, while pin 9 is high, pins 10 and 11 go high due to the operation of the speed signal level detector (Q3 pin 12 goes low) then pin 8 of Q4 will go low. With Q4 pin 8 low, pin 6 goes high to turn Q9 and Q10 on. When the transistors turn ON, relays RE-5 and RE-6 and the LED all operate.

Timer #1 output stays high for 300 ms or for as long as Q2 and Q8 remain operated, whichever is longer. The purpose of this timer is to "remember" for a set period of time the fact that both Q2 and Q8 have operated. It is possible that for some fault, for which an operation of the TSEC is desired, the voltage regulator and terminal voltage detectors will operate and reset before the speed detector has had a change to operate due to inertia of the generator.

Timer #2, set for a seal-in time of approximately 3 s, and triggered through capacitor C14 forces relays RE-5 and RE-6 to drop out after a fixed time delay, no matter what the state of the three level detectors.

The output of Q4, pin 8 is used as a seal-in path for Q4, pin 12. This seal-in is required to keep the TSEC operated when terminal voltage goes above rated value.

The reset of either the voltage regulator detector or speed signal detector will cause a reset of the logic.

Zener diode D14 prevents relay RE-6 from picking up while the stabilizer is being powered up or down. On the power up the outputs of the NAND gates shift randomly while the +ve supply is changing. Zener diode D12 limits the operating voltage of the reed relay RE-5 to 5 V, the nominal rating of the coil.

#### 4.15 115 V ac Supply Considerations

The +15 V power supply requires an input of 115 V ac and the stabilizers draws about 150 ma. This supply must be more reliable than the supply to the excitation system and must not be

interrupted while the stabilizer is in service. At Bruce, power is provided from the 115 V generator PTs.

To limit the effect of high frequency transients, a capacitor and a filter are connected across the supply.

As described in Section 4.10 the stabilizer supply has been designed to ride through system fault conditions.

#### 4.16 Wiring and Card Interconnections (Schematic: Figure 4-18)

The stabilizer consists of two racks of cards mounted in a doubly shielded enclosure. The inner enclosure is tied to the common of the stabilizer power supply (signal common) and the outer case is grounded. High frequency filtering for the 115 V ac circuits is located behind the card racks. The numbers of Figure 4-18 are the card edge connector pin numbers and correspond to those shown on the schematics.

All wiring to and from the stabilizer is shown in Figure 4-18. More complete wiring details are provided in the station drawings listed in Section 5.

As the voltage regulator is grounded at one point only, it is important to ensure that the stabilizer inner case is not grounded.

In 1983/83 dynamic test facilities were retrofitted on the  $\Delta\omega$  stabilizers and in 1984/85 TSEC facilities were added. These retrofits have necessitated changes in the back wiring of the stabilizer cases and the addition of some extra signal cables. It is important that the back wiring of all the  $\Delta\omega$  stabilizers at Bruce 'A' be made to conform to the schematic of Figure 4-18. This work should have been done as the TSEC facilities were added to each unit.

Card layout in the case must be as shown in Figure 4-19. Cards are not keyed and could be inserted in a wrong location if care is not exercised in installing them.

#### 4.17 Protection Logic

The  $\Delta\omega$  stabilizer will automatically turn off if the speed signal circuit fails, if the +15 V power supply fails or if the unit breaker is opened. Figure 4-20 shows the behaviour of various protection logic test points for these different

events. Note that the traces are not intended to be represented as a function of time (that is, the signals are not square wave).

#### 4.18 Typical Waveforms

Figures 4-21 and 4-22 show typical waveforms which can be measured on the different test points of each card. Where no waveforms are shown for a given test point, the signal should be easily determined from the printed circuit card description in earlier sections.

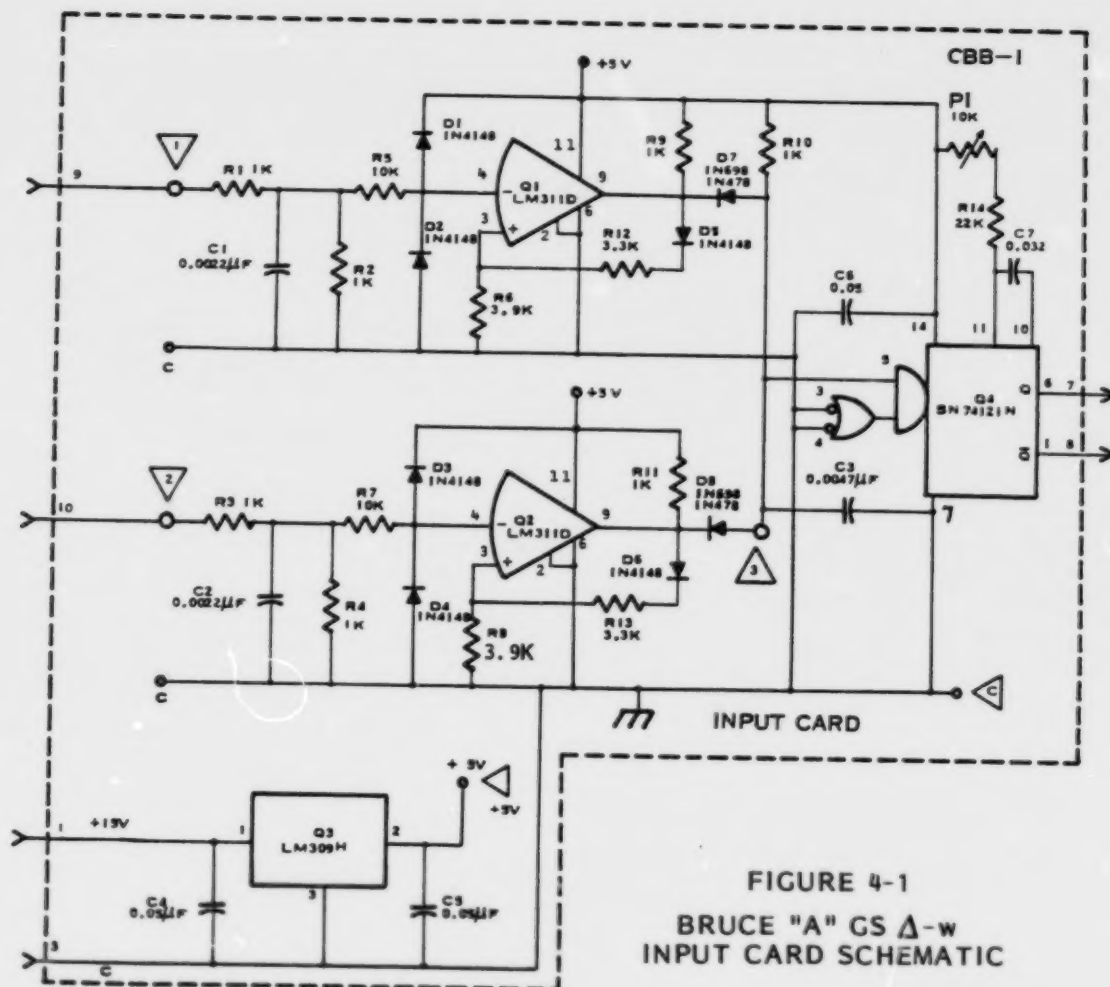
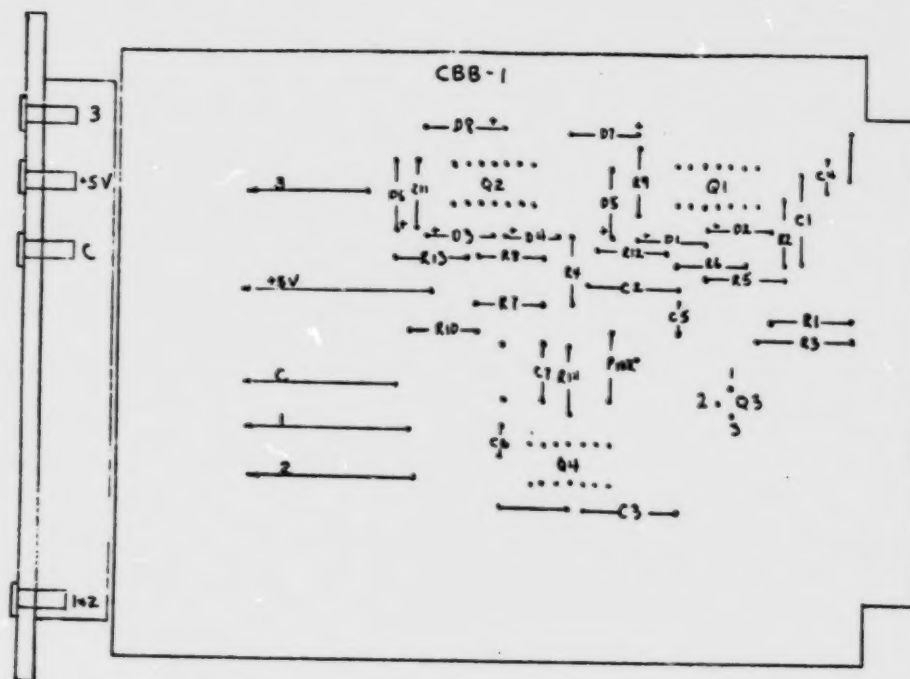
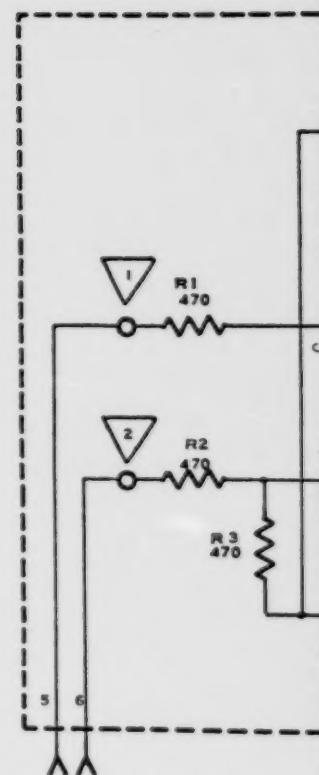
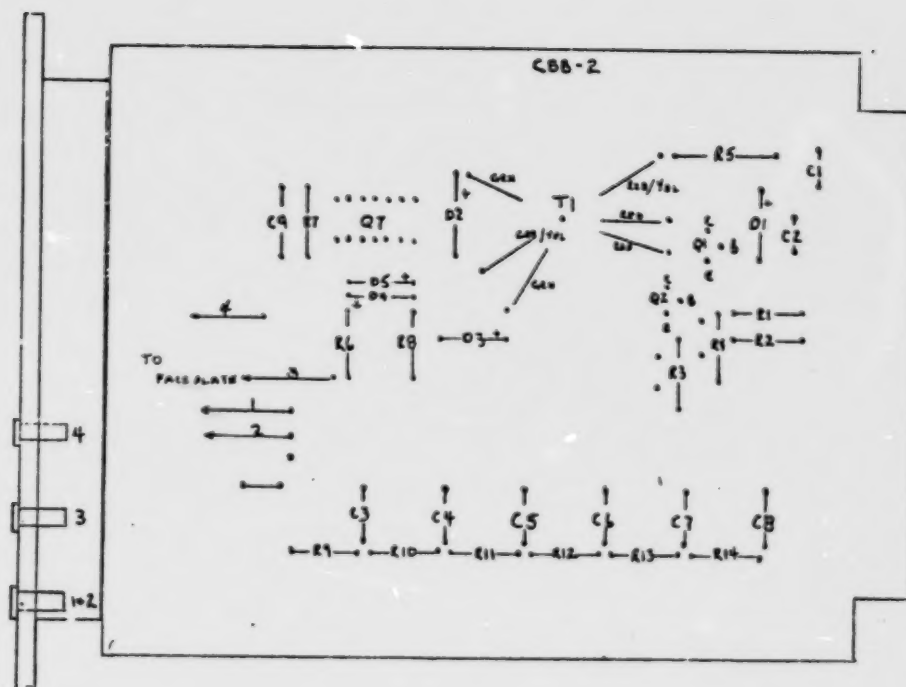


FIGURE 4-1  
BRUCE "A" GS Δ-w  
INPUT CARD SCHEMATIC





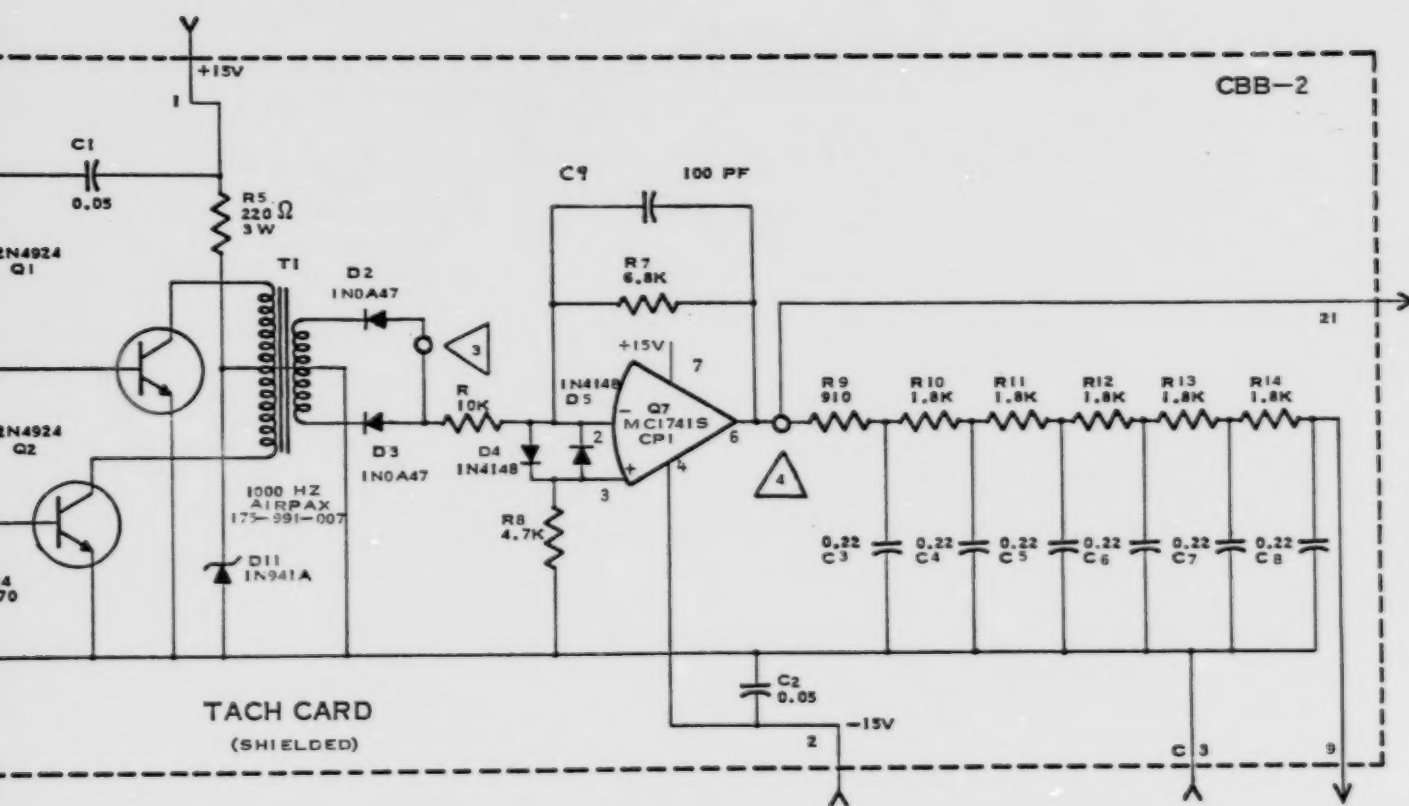
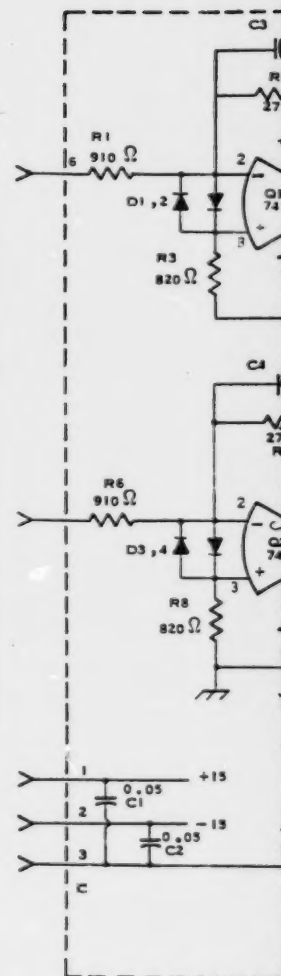
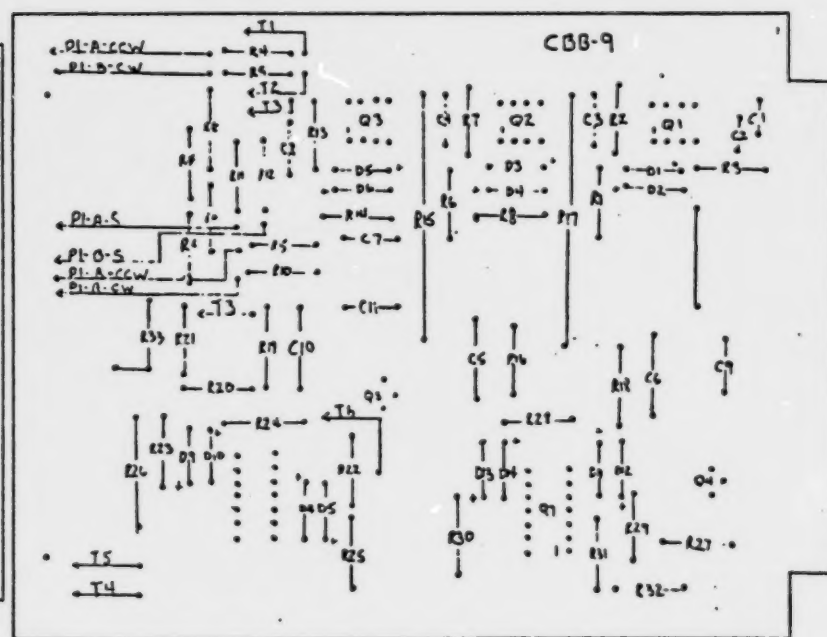
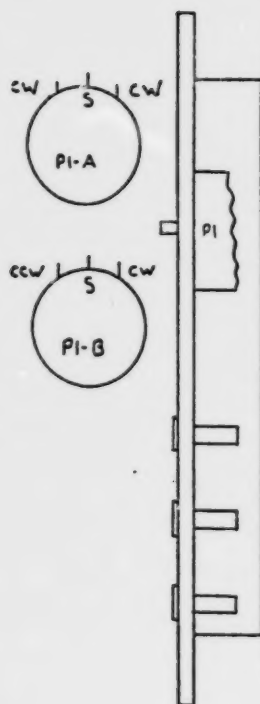


FIGURE 4-2  
BRUCE "A" GS  $\Delta-w$   
TACH CARD SCHEMATIC



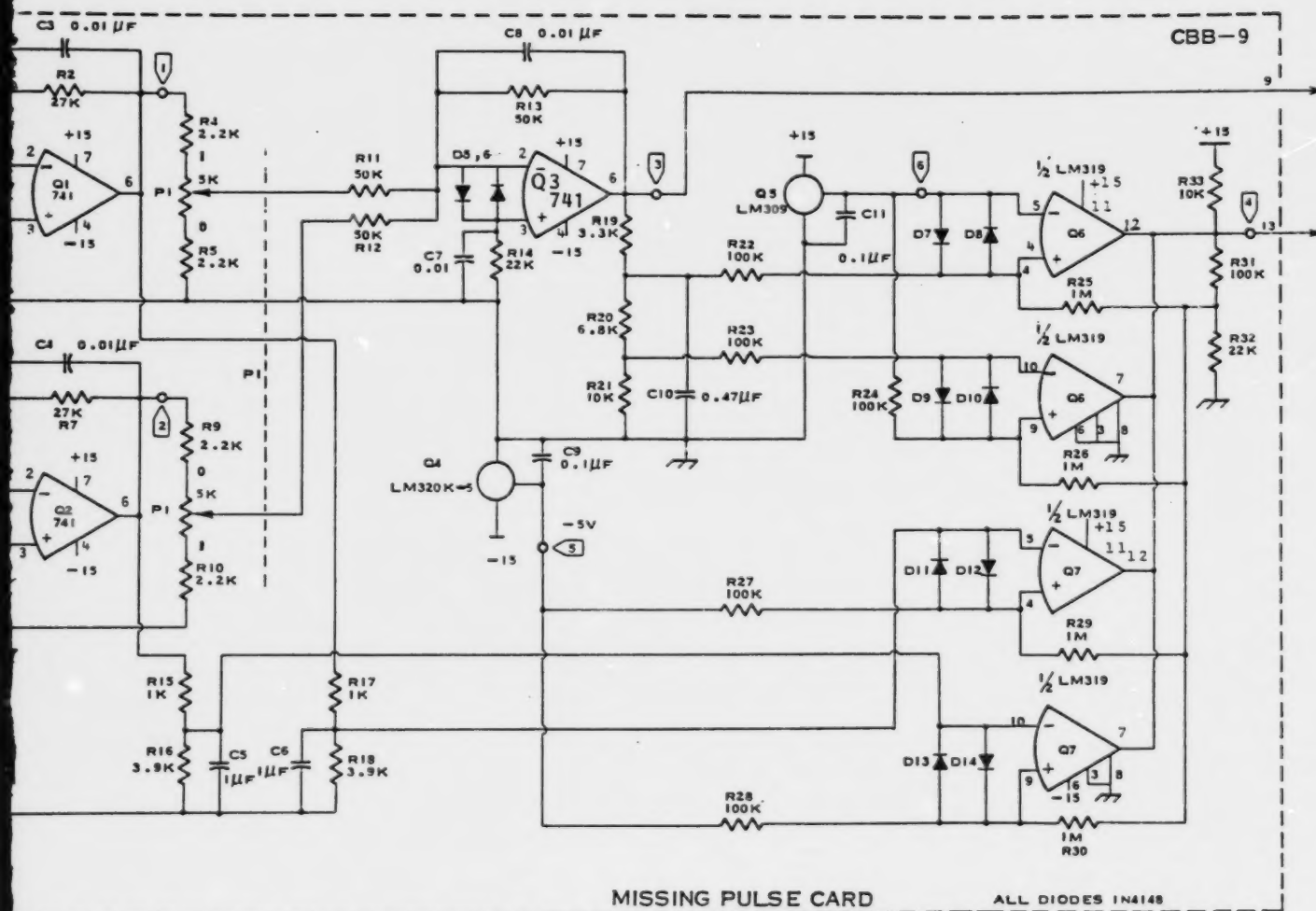
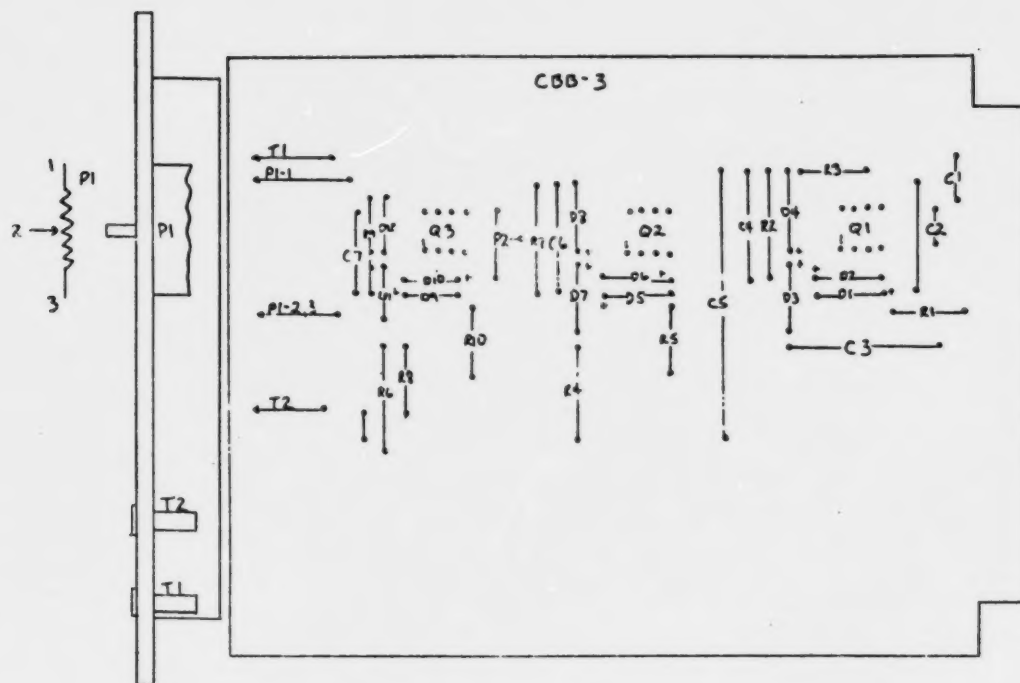


FIGURE 4-3  
BRUCE "A" GS  $\Delta$ -w  
MISSING PULSE CARD SCHEMATIC



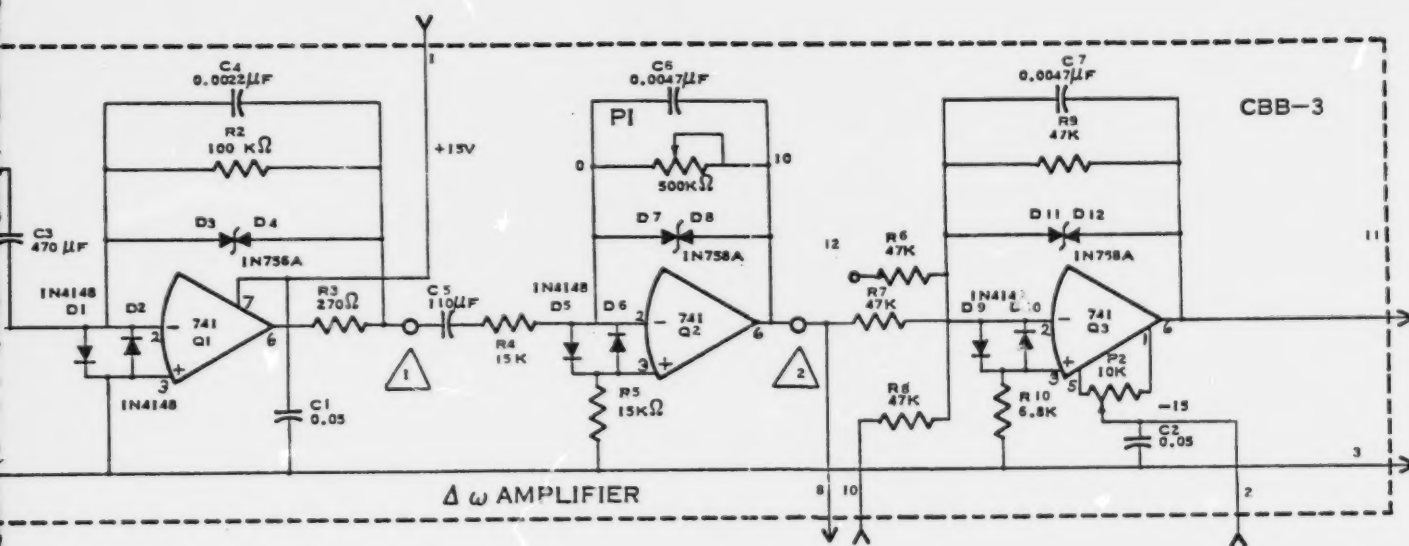
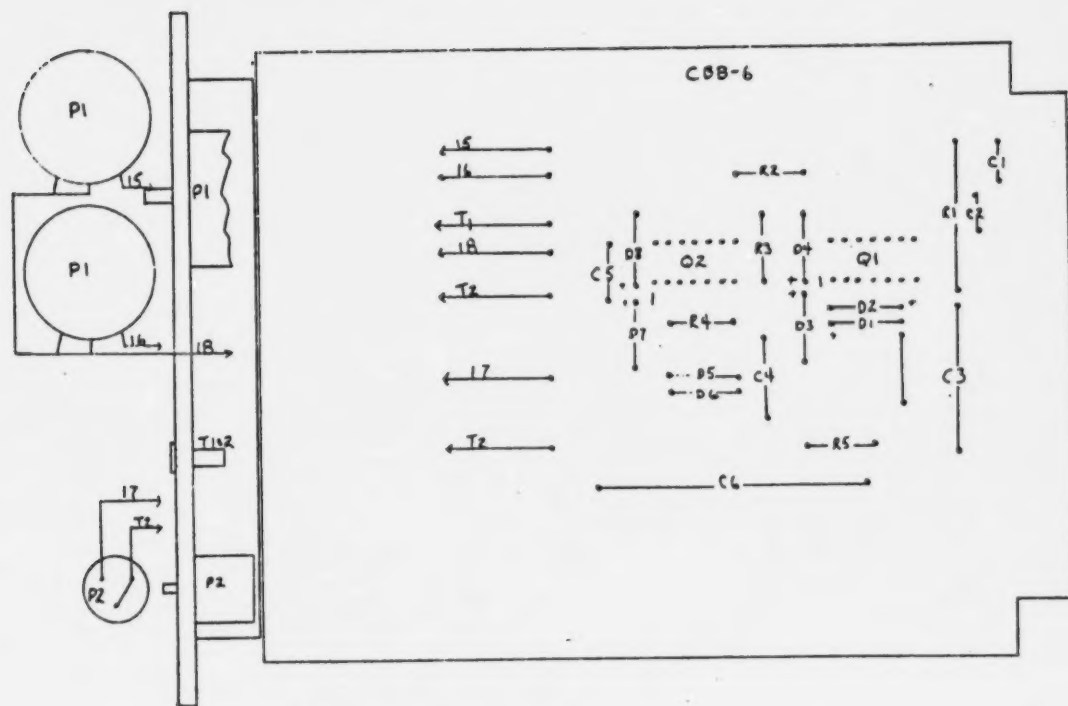


FIGURE 4-4

BRUCE "A" GS  $\Delta - \omega$   
DELTA-OMEGA AMP CARD SCHEMATIC





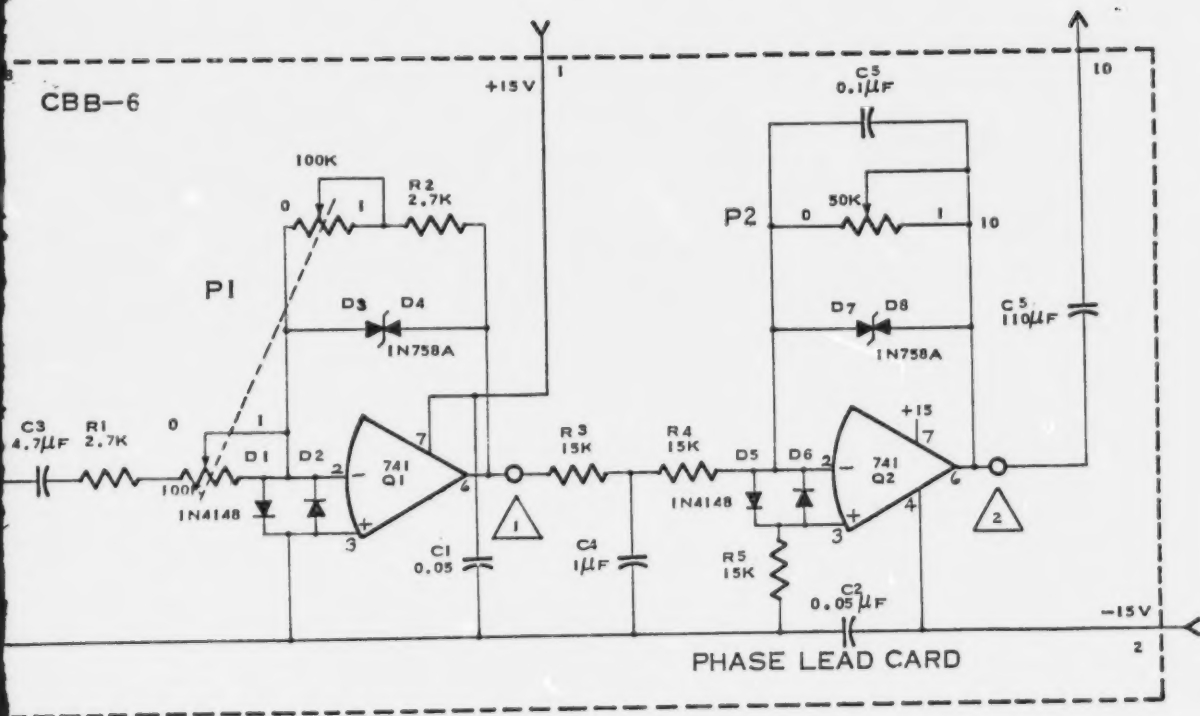


FIGURE 4-5  
BRUCE "A" GS  $\Delta-\omega$   
PHASE LEAD CARD SCHEMATIC

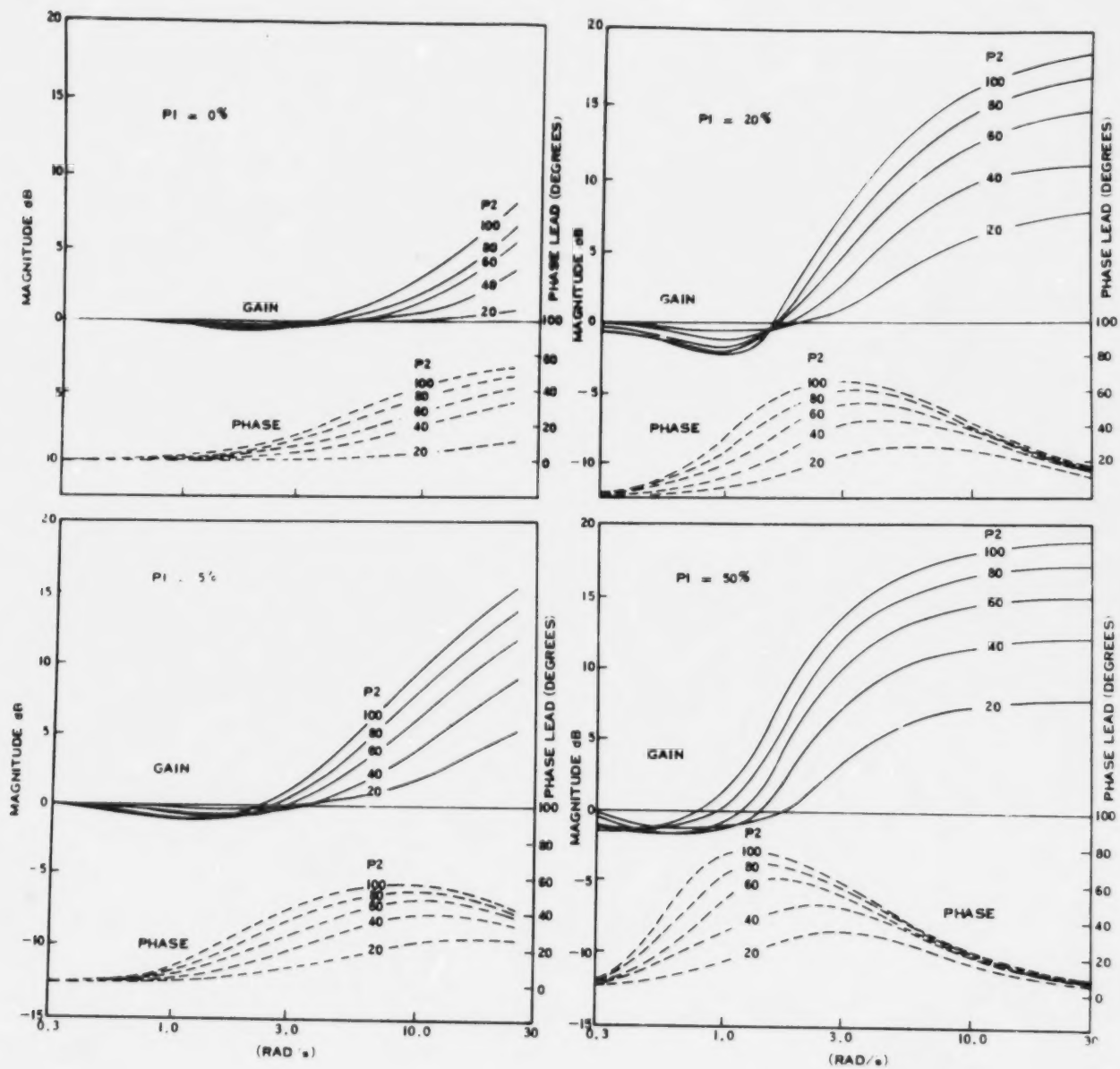
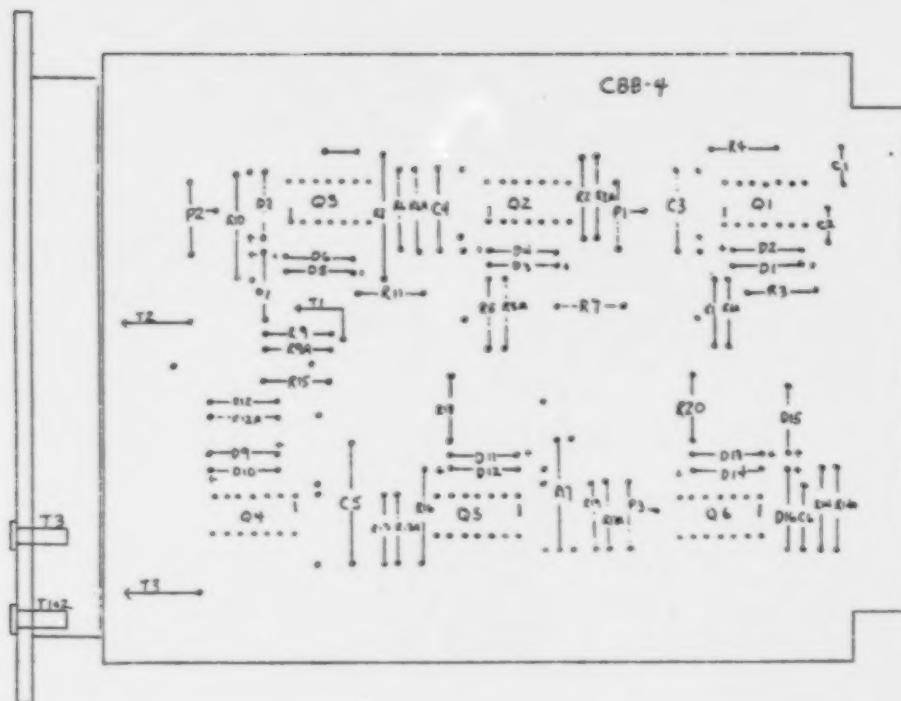


FIGURE 4-6  
PHASE LEAD CIRCUIT CHARACTERISTICS  
BRUCE "A" GS -  $\Delta \omega$



NOTE -

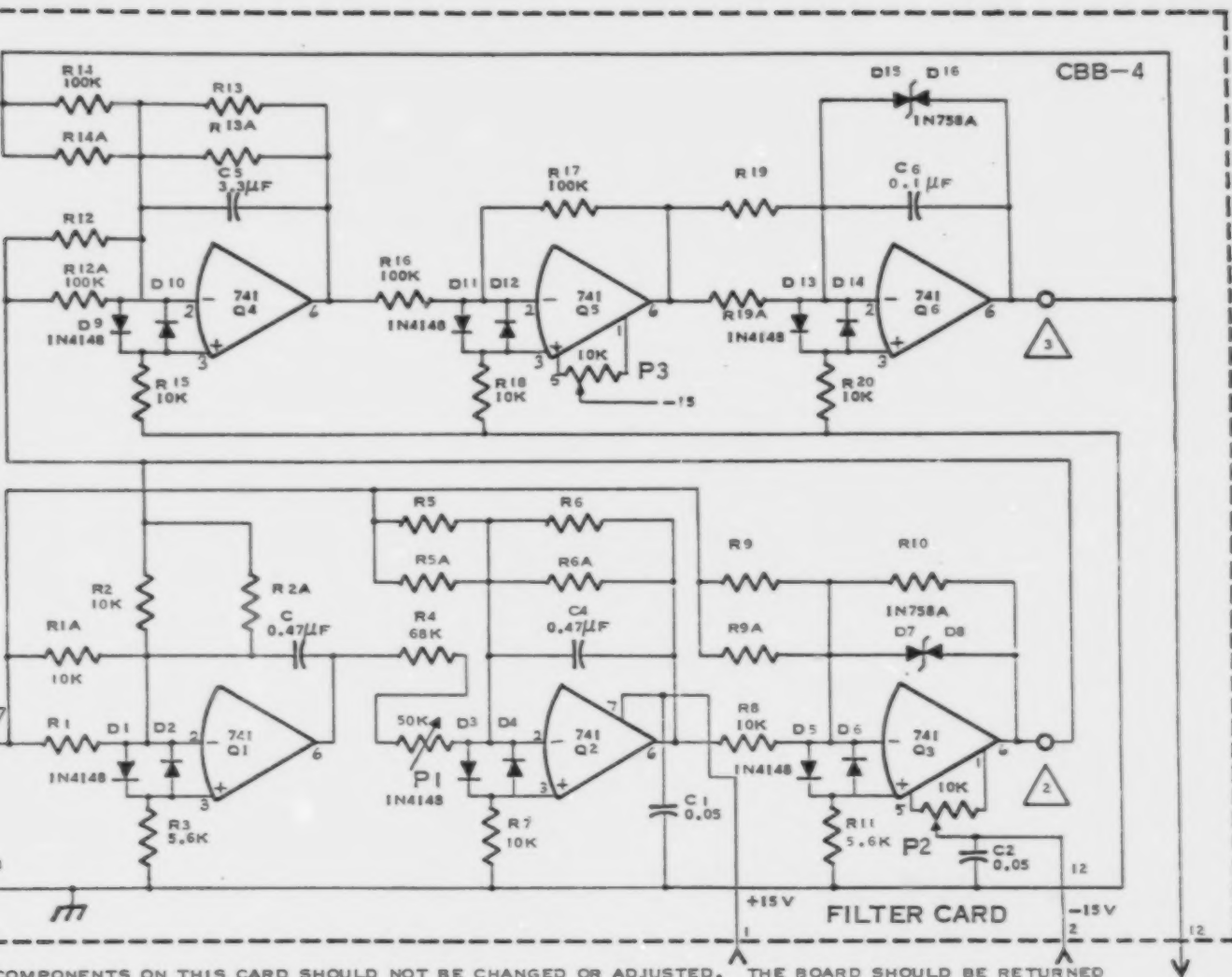


FIGURE 4-7  
BRUCE "A" GS 1- $\omega$   
FILTER CARD SCHEMATIC

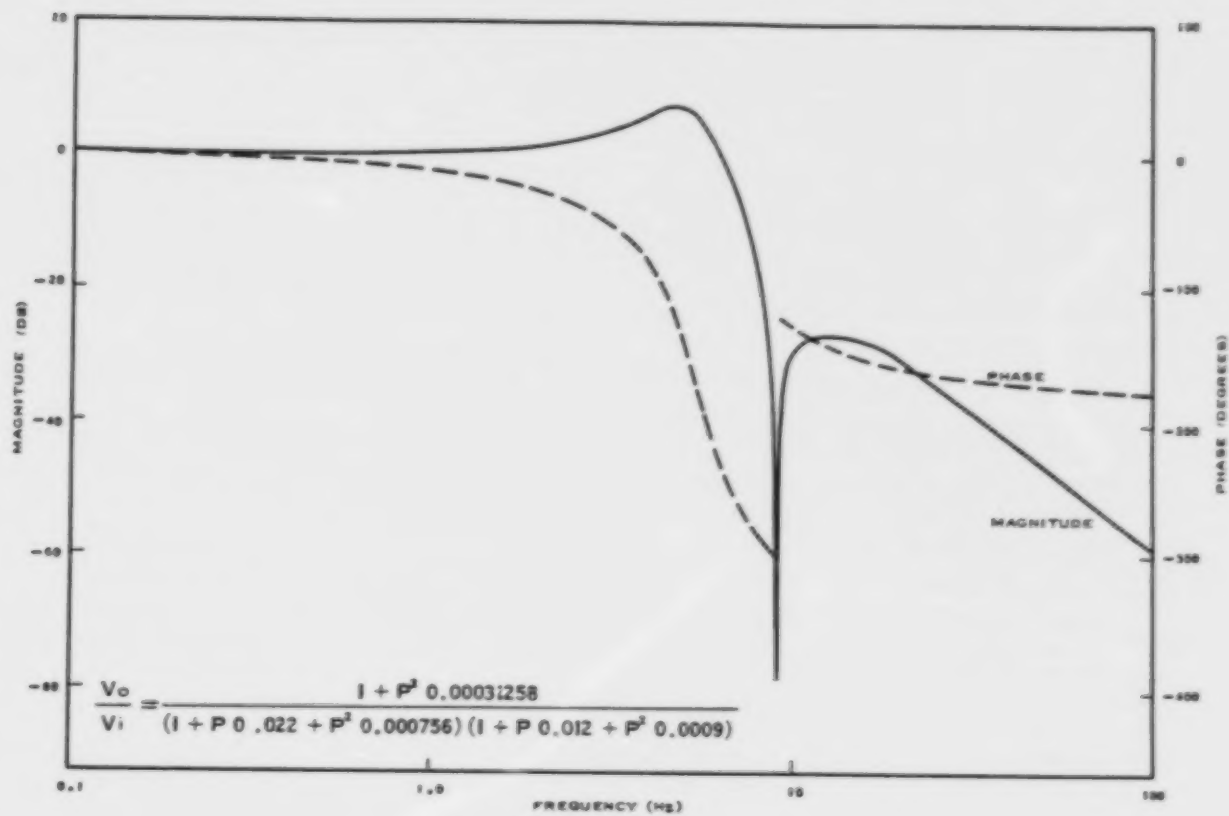


FIGURE 4-8  
TORSIONAL FILTER FOR BRUCE DELTA-OMEGA STABILIZER



# VOLTAGE LIMITER

R-5, R-15, R17 SELECTED

C6, R21, D12, C4, R8, C7, R14 : NOT INSTALLED

Q4 AND ASSOCIATE COMPONENTS : FOR BRUCE A  $\Delta\omega$  STAB. ONLY

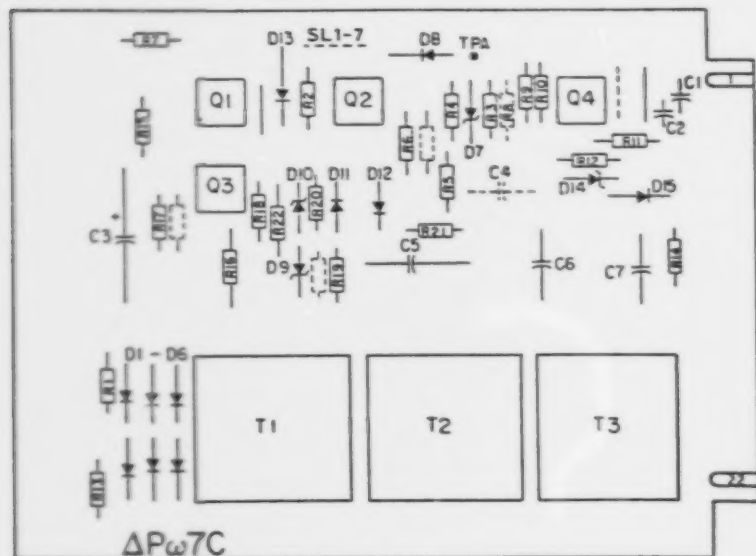
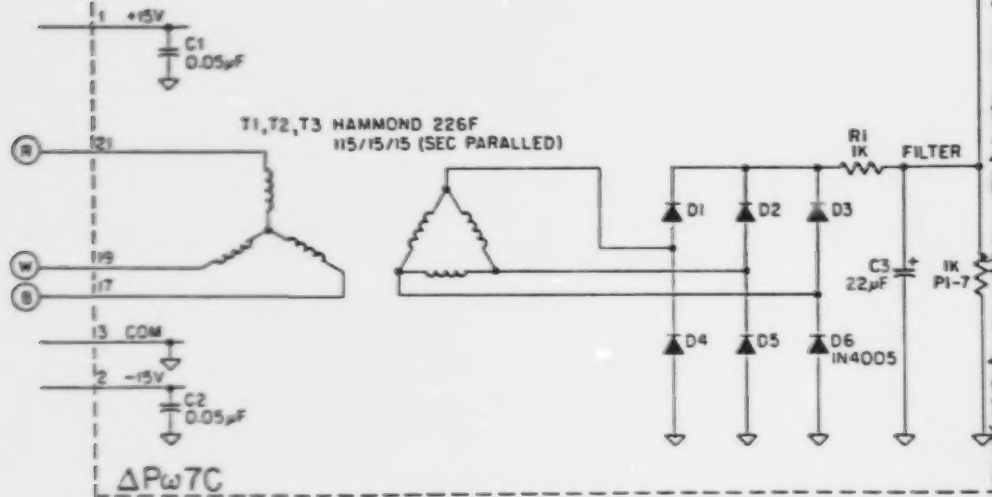
SL1-7 : USED WHEN Q4 NOT INSTALLED

LOW LIMIT = 1.07 AT NANTICOKE

= 1.10 AT OTHER STATIONS

HIGH LIMIT = 1.10 AT NANTICOKE

= 1.15 AT OTHER STATIONS



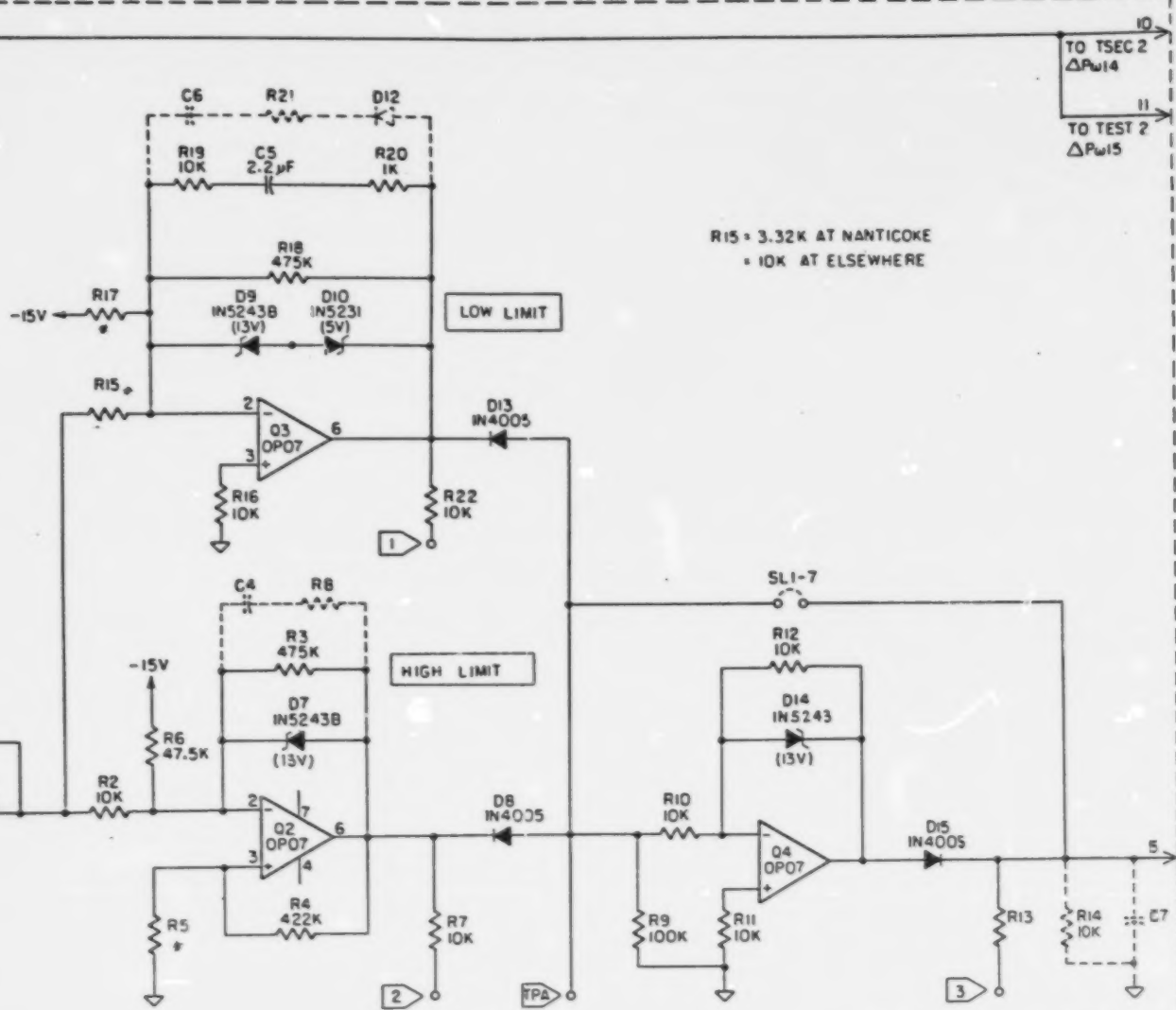


FIGURE 4-9  
 TERMINAL VOLTAGE LIMITER CARD -  $\Delta PW7C$   
 (USED WITH TSEC OPTION)  
 REVISED MAY 13, 1985

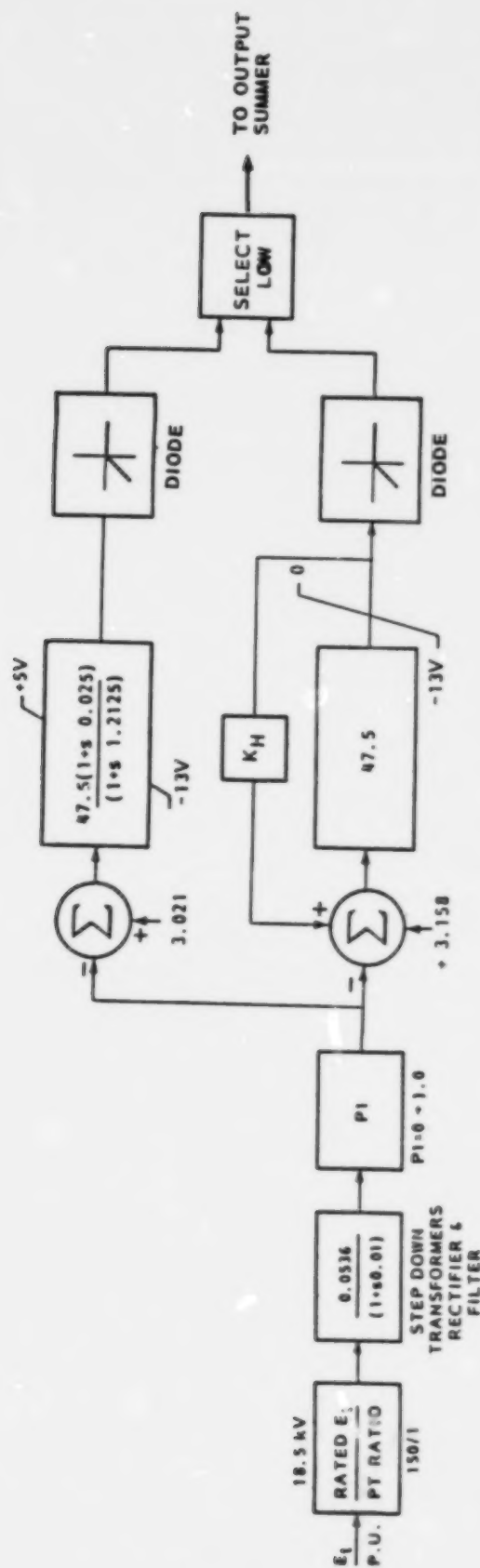
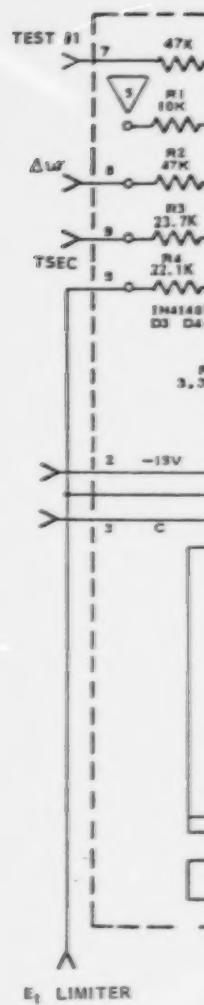
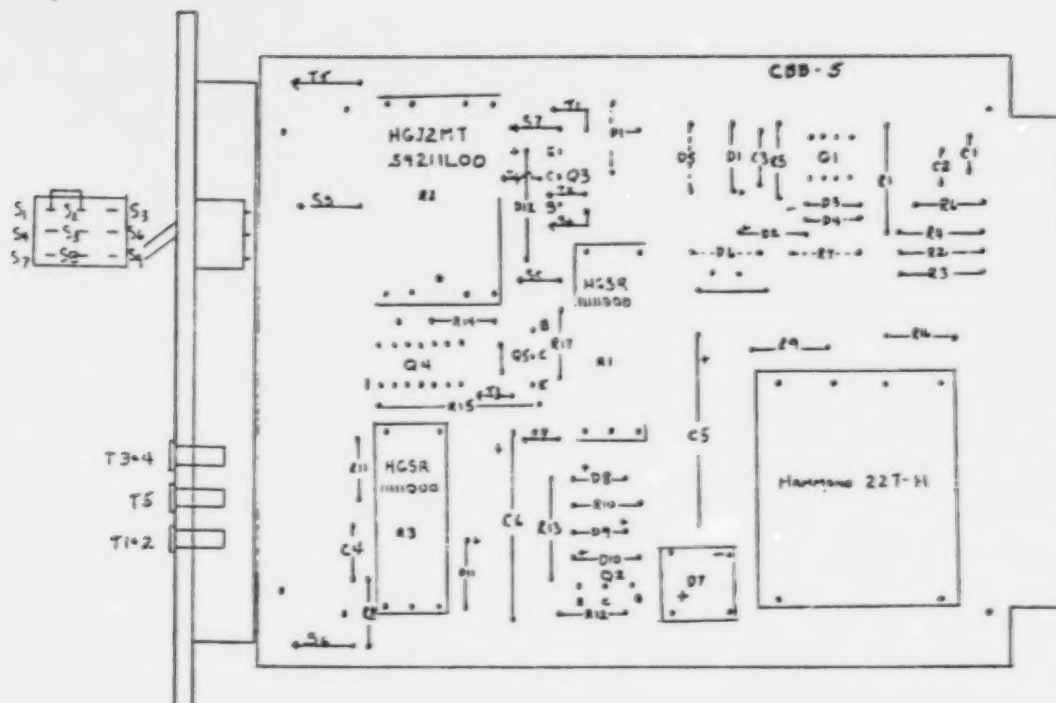


FIGURE 4-10  
BLOCK DIAGRAM REPRESENTATION OF THE TERMINAL  
VOLTAGE TRANSDUCER AND LIMITER CARD  
BRUCE "A" GS -  $\Delta\omega$  STABILIZER



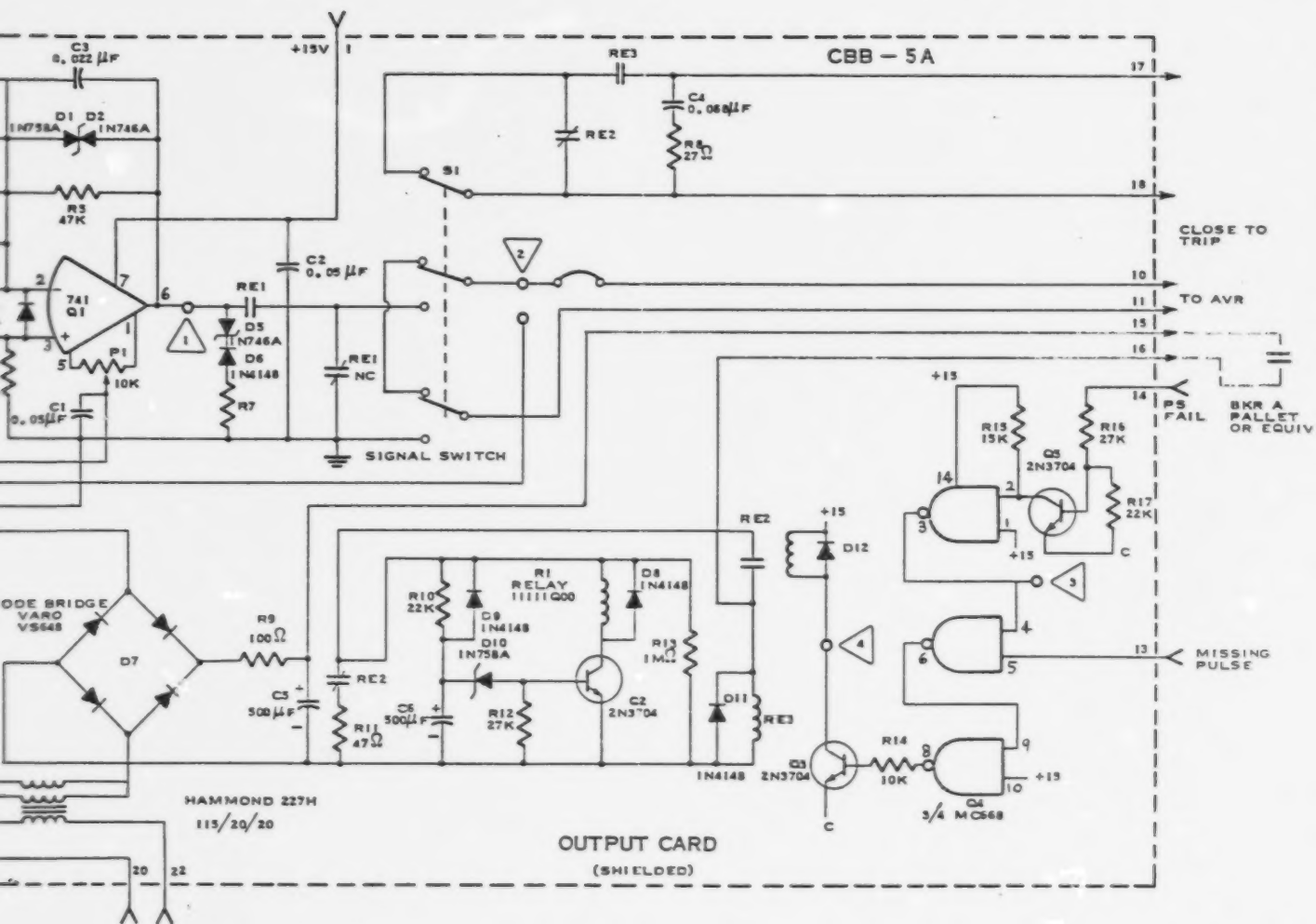
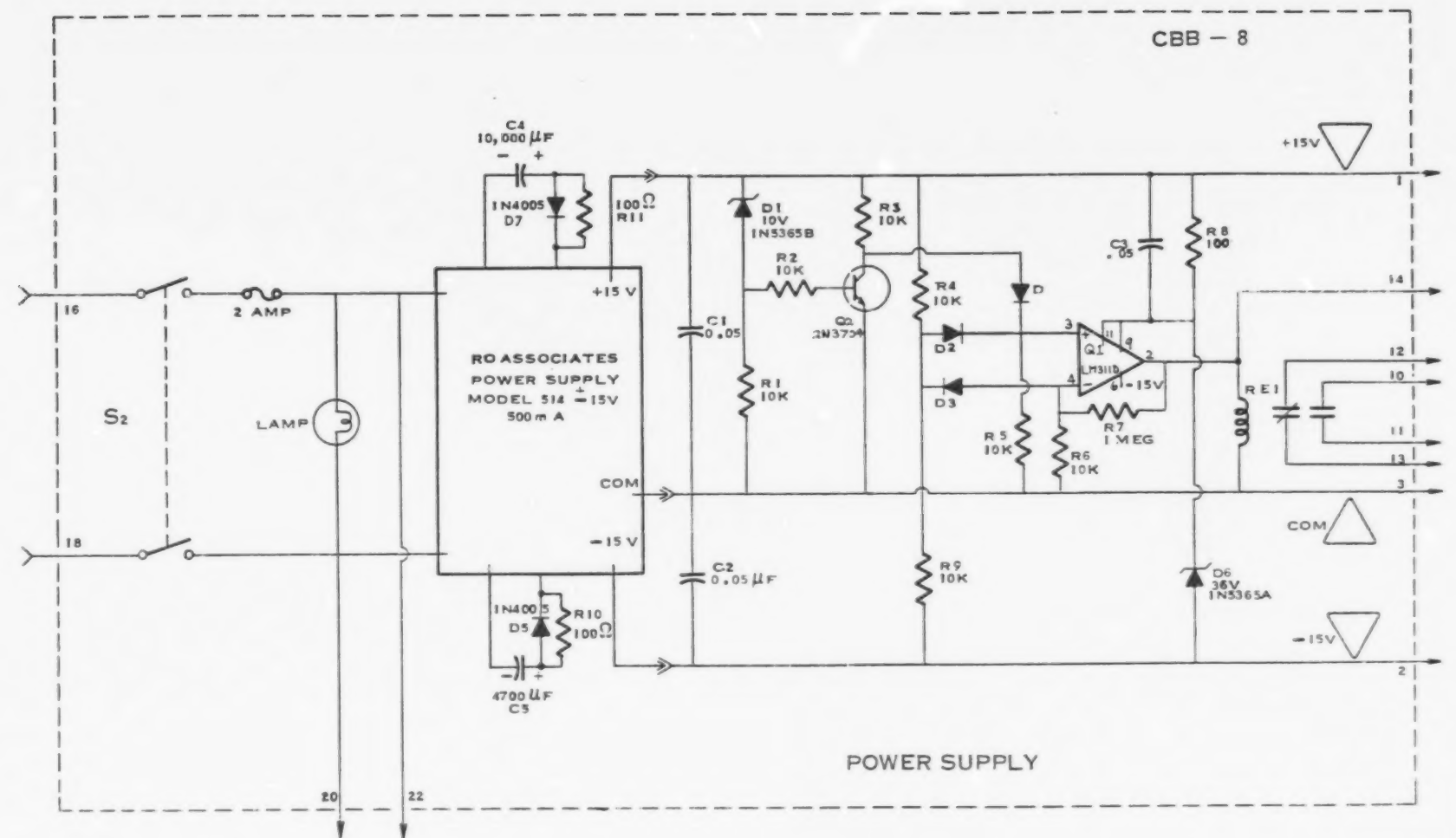


FIGURE 4-11  
BRUCE "A" GS  $\Delta - \omega$   
OUTPUT CARD SCHEMATIC



200334 RD



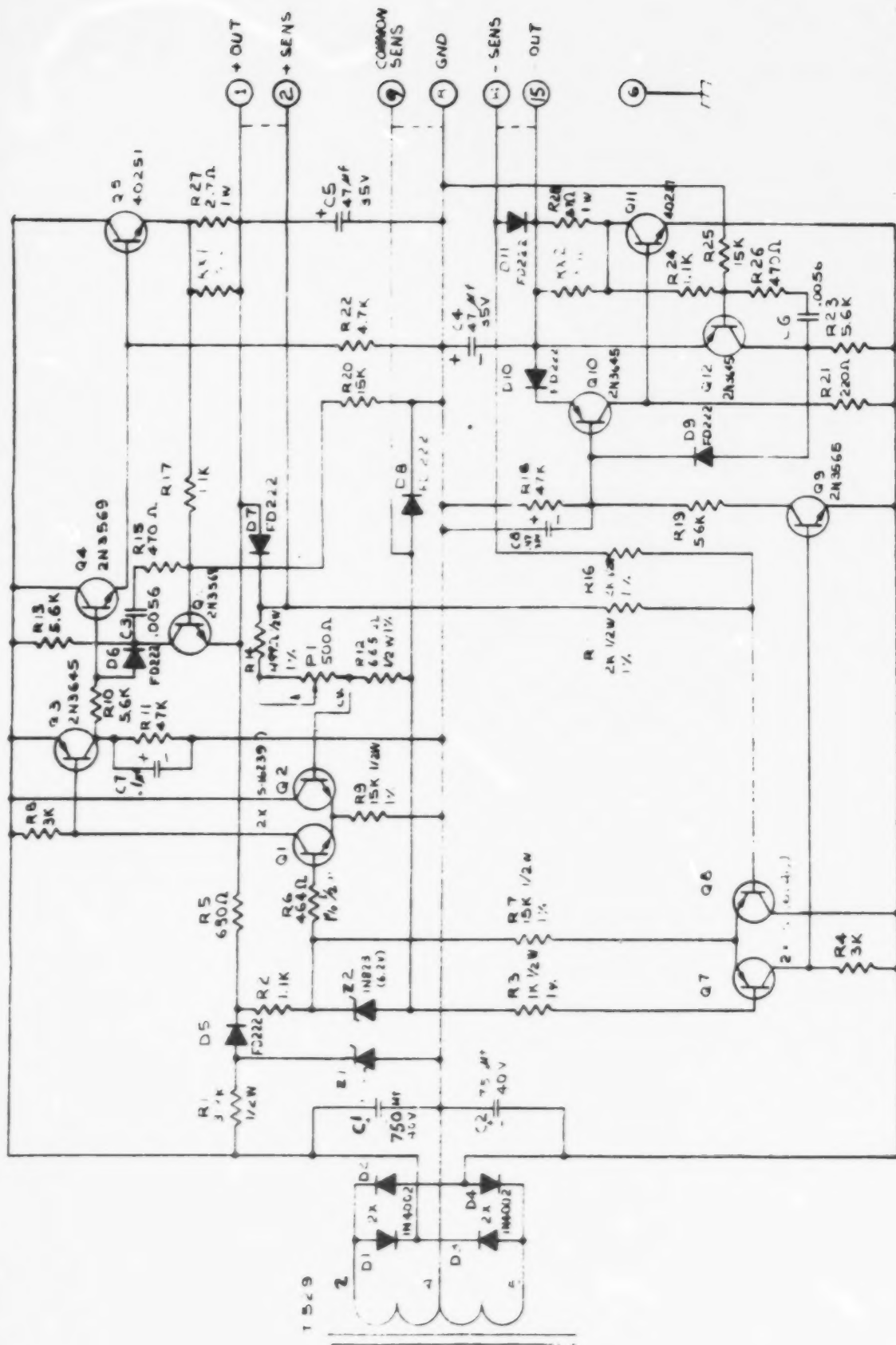
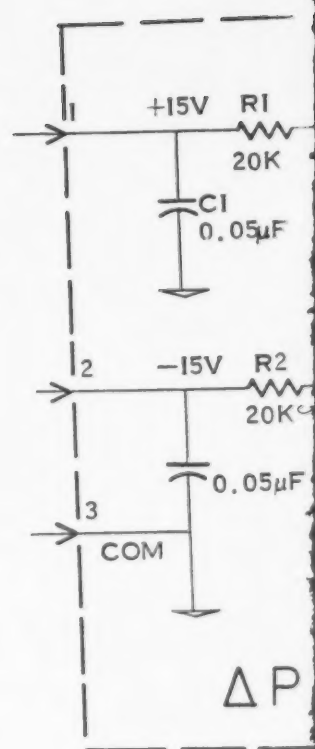
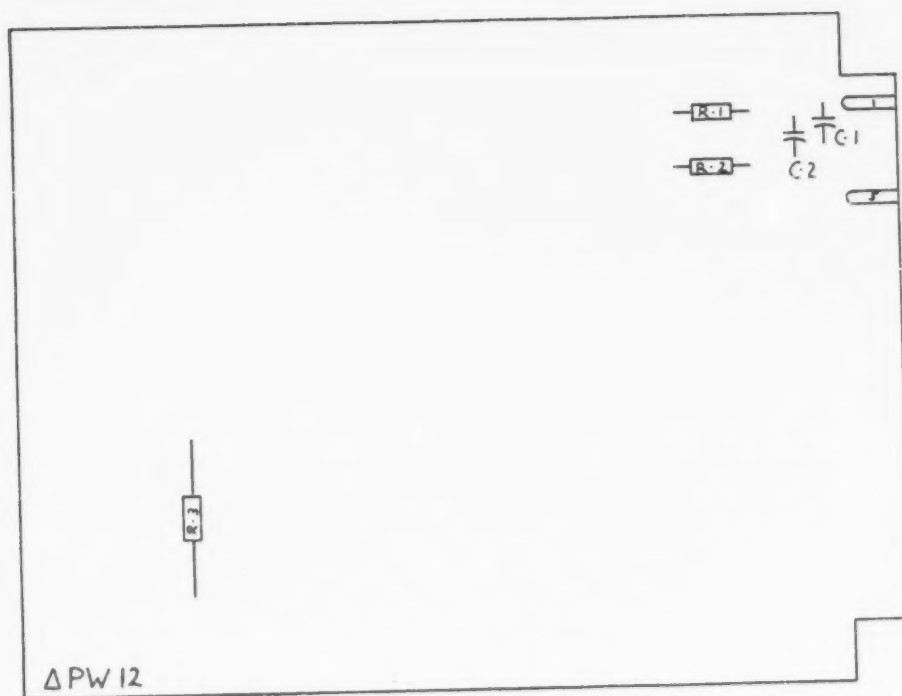


FIGURE 4-13

|      |    |    |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |  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    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|------|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|----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| ITEM | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 | Q13 | Q14 | Q15 | Q16 | Q17 | Q18 | Q19 | Q20 | Q21 | Q22 | Q23 | Q24 | Q25 | Q26 | Q27 | Q28 | Q29 | Q30 | Q31 | Q32 | Q33 | Q34 | Q35 | Q36 | Q37 | Q38 | Q39 | Q40 | Q41 | Q42 | Q43 | Q44 | Q45 | Q46 | Q47 | Q48 | Q49 | Q50 | Q51 | Q52 | Q53 | Q54 | Q55 | Q56 | Q57 | Q58 | Q59 | Q60 | Q61 | Q62 | Q63 | Q64 | Q65 | Q66 | Q67 | Q68 | Q69 | Q70 | Q71 | Q72 | Q73 | Q74 | Q75 | Q76 | Q77 | Q78 | Q79 | Q80 | Q81 | Q82 | Q83 | Q84 | Q85 | Q86 | Q87 | Q88 | Q89 | Q90 | Q91 | Q92 | Q93 | Q94 | Q95 | Q96 | Q97 | Q98 | Q99 | Q100 | Q101 | Q102 | Q103 | Q104 | Q105 | Q106 | Q107 | Q108 | Q109 | Q110 | Q111 | Q112 | Q113 | Q114 | Q115 | Q116 | Q117 | Q118 | Q119 | Q120 | Q121 | Q122 | Q123 | Q124 | Q125 | Q126 | Q127 | Q128 | Q129 | Q130 | Q131 | Q132 | Q133 | Q134 | Q135 | Q136 | Q137 | Q138 | Q139 | Q140 | Q141 | Q142 | Q143 | Q144 | Q145 | Q146 | Q147 | Q148 | Q149 | Q150 | Q151 | Q152 | Q153 | Q154 | Q155 | Q156 | Q157 | Q158 | Q159 | Q160 | Q161 | Q162 | Q163 | Q164 | Q165 | Q166 | Q167 | Q168 | Q169 | Q170 | Q171 | Q172 | Q173 | Q174 | Q175 | Q176 | Q177 | Q178 | Q179 | Q180 | Q181 | Q182 | Q183 | Q184 | Q185 | Q186 | Q187 | Q188 | Q189 | Q190 | Q191 | Q192 | Q193 | Q194 | Q195 | Q196 | Q197 | Q198 | Q199 | Q200 | Q201 | Q202 | Q203 | Q204 | Q205 | Q206 | Q207 | Q208 | Q209 | Q210 | Q211 | Q212 | Q213 | Q214 | Q215 | Q216 | Q217 | Q218 | Q219 | Q220 | Q221 | Q222 | Q223 | Q224 | Q225 | Q226 | Q227 | Q228 | Q229 | Q230 | Q231 | Q232 | Q233 | Q234 | Q235 | Q236 | Q237 | Q238 | Q239 | Q240 | Q241 | Q242 | Q243 | Q244 | Q245 | Q246 | Q247 | Q248 | Q249 | Q250 | Q251 | Q252 | Q253 | Q254 | Q255 | Q256 | Q257 | Q258 | Q259 | Q260 | Q261 | Q262 | Q263 | Q264 | Q265 | Q266 | Q267 | Q268 | Q269 | Q270 | Q271 | Q272 | Q273 | Q274 | Q275 | Q276 | Q277 | Q278 | Q279 | Q280 | Q281 | Q282 | Q283 | Q284 | Q285 | Q286 | Q287 | Q288 | Q289 | Q290 | Q291 | Q292 | Q293 | Q294 | Q295 | Q296 | Q297 | Q298 | Q299 | Q300 | Q301 | Q302 | Q303 | Q304 | Q305 | Q306 | Q307 | Q308 | Q309 | Q310 | Q311 | Q312 | Q313 | Q314 | Q315 | Q316 | Q317 | Q318 | Q319 | Q320 | Q321 | Q322 | Q323 | Q324 | Q325 | Q326 | Q327 | Q328 | Q329 | Q330 | Q331 | Q332 | Q333 | Q334 | Q335 | Q336 | Q337 | Q338 | Q339 | Q340 | Q341 | Q342 | Q343 | Q344 | Q345 | Q346 | Q347 | Q348 | Q349 | Q350 | Q351 | Q352 | Q353 | Q354 | Q355 | Q356 | Q357 | Q358 | Q359 | Q360 | Q361 | Q362 | Q363 | Q364 | Q365 | Q366 | Q367 | Q368 | Q369 | Q370 | Q371 | Q372 | Q373 | Q374 | Q375 | Q376 | Q377 | Q378 | Q379 | Q380 | Q381 | Q382 | Q383 | Q384 | Q385 | Q386 | Q387 | Q388 | Q389 | Q390 | Q391 | Q392 | Q393 | Q394 | Q395 | Q396 | Q397 | Q398 | Q399 | Q400 | Q401 | Q402 | Q403 | Q404 | Q405 | Q406 | Q407 | Q408 | Q409 | Q410 | Q411 | Q412 | Q413 | Q414 | Q415 | Q416 | Q417 | Q418 | Q419 | Q420 | Q421 | Q422 | Q423 | Q424 | Q425 | Q426 | Q427 | Q428 | Q429 | Q430 | Q431 | Q432 | Q433 | Q434 | Q435 | Q436 | Q437 | Q438 | Q439 | Q440 | Q441 | Q442 | Q443 | Q444 | Q445 | Q446 | Q447 | Q448 | Q449 | Q450 | Q451 | Q452 | Q453 | Q454 | Q455 | Q456 | Q457 | Q458 | Q459 | Q460 | Q461 | Q462 | Q463 | Q464 | Q465 | Q466 | Q467 | Q468 | Q469 | Q470 | Q471 | Q472 | Q473 | Q474 | Q475 | Q476 | Q477 | Q478 | Q479 | Q480 | Q481 | Q482 | Q483 | Q484 | Q485 | Q486 | Q487 | Q488 | Q489 | Q490 | Q491 | Q492 | Q493 | Q494 | Q495 | Q496 | Q497 | Q498 | Q499 | Q500 | Q501 | Q502 | Q503 | Q504 | Q505 | Q506 | Q507 | Q508 | Q509 | Q510 | Q511 | Q512 | Q513 | Q514 | Q515 | Q516 | Q517 | Q518 | Q519 | Q520 | Q521 | Q522 | Q523 | Q524 | Q525 | Q526 | Q527 | Q528 | Q529 | Q530 | Q531 | Q532 | Q533 | Q534 | Q535 | Q536 | Q537 | Q538 | Q539 | Q540 | Q541 | Q542 | Q543 | Q544 | Q545 | Q546 | Q547 | Q548 | Q549 | Q550 | Q551 | Q552 | Q553 | Q554 | Q555 | Q556 | Q557 | Q558 | Q559 | Q560 | Q561 | Q562 | Q563 | Q564 | Q565 | Q566 | Q567 | Q568 | Q569 | Q570 | Q571 | Q572 | Q573 | Q574 | Q575 | Q576 | Q577 | Q578 | Q579 | Q580 | Q581 | Q582 | Q583 | Q584 | Q585 | Q586 | Q587 | Q588 | Q589 | Q590 | Q591 | Q592 | Q593 | Q594 | Q595 | Q596 | Q597 | Q598 | Q599 | Q600 | Q601 | Q602 | Q603 | Q604 | Q605 | Q606 | Q607 | Q608 | Q609 | Q610 | Q611 | Q612 | Q613 | Q614 | Q615 | Q616 | Q617 | Q618 | Q619 | Q620 | Q621 | Q622 | Q623 | Q624 | Q625 | Q626 | Q627 | Q628 | Q629 | Q630 | Q631 | Q632 | Q633 | Q634 | Q635 | Q636 | Q637 | Q638 | Q639 | Q640 | Q641 | Q642 | Q643 | Q644 | Q645 | Q646 | Q647 | Q648 | Q649 | Q650 | Q651 | Q652 | Q653 | Q654 | Q655 | Q656 | Q657 | Q658 | Q659 | Q660 | Q661 | Q662 | Q663 | Q664 | Q665 | Q666 | Q667 | Q668 | Q669 | Q670 | Q671 | Q672 | Q673 | Q674 | Q675 | Q676 | Q677 | Q678 | Q679 | Q680 | Q681 | Q682 | Q683 | Q684 | Q685 | Q686 | Q687 | Q688 | Q689 | Q690 | Q691 | Q692 | Q693 | Q694 | Q695 | Q696 | Q697 | Q698 | Q699 | Q700 | Q701 | Q702 | Q703 | Q704 | Q705 | Q706 | Q707 | Q708 | Q709 | Q710 | Q711 | Q712 | Q713 | Q714 | Q715 | Q716 | Q717 | Q718 | Q719 | Q720 | Q721 | Q722 | Q723 | Q724 | Q725 | Q726 | Q727 | Q728 | Q729 | Q730 | Q731 | Q732 | Q733 | Q734 | Q735 | Q736 | Q737 | Q738 | Q739 | Q740 | Q741 | Q742 | Q743 | Q744 | Q745 | Q746 | Q747 | Q748 | Q749 | Q750 | Q751 | Q752 | Q753 | Q754 | Q755 | Q756 | Q757 | Q758 | Q759 | Q760 | Q761 | Q762 | Q763 | Q764 | Q765 | Q766 | Q767 | Q768 | Q769 | Q770 | Q771 | Q772 | Q773 | Q774 | Q775 | Q776 | Q777 | Q778 | Q779 | Q780 | Q781 | Q782 | Q783 | Q784 | Q785 | Q786 | Q787 | Q788 | Q789 | Q790 | Q791 | Q792 | Q793 | Q794 | Q795 | Q796 | Q797 | Q798 | Q799 | Q800 | Q801 | Q802 | Q803 | Q804 | Q805 | Q806 | Q807 | Q808 | Q809 | Q810 | Q811 | Q812 | Q813 | Q814 | Q815 | Q816 | Q817 | Q818 | Q819 | Q820 | Q821 | Q822 | Q823 | Q824 | Q825 | Q826 | Q827 | Q828 | Q829 | Q830 | Q831 | Q832 | Q833 | Q834 | Q835 | Q836 | Q837 | Q838 | Q839 | Q840 | Q841 | Q842 | Q843 | Q844 | Q845 | Q846 | Q847 | Q848 | Q849 | Q850 | Q851 | Q852 | Q853 | Q854 | Q855 | Q856 | Q857 | Q858 | Q859 | Q860 | Q861 | Q862 | Q863 | Q864 | Q865 | Q866 | Q867 | Q868 | Q869 | Q870 | Q871 | Q872 | Q873 | Q874 | Q875 | Q876 | Q877 | Q878 | Q879 | Q880 | Q881 | Q882 | Q883 | Q884 | Q885 | Q886 | Q887 | Q888 | Q889 | Q890 | Q891 | Q892 | Q893 | Q894 | Q895 | Q896 | Q897 | Q898 | Q899 | Q900 | Q901 | Q902 | Q903 | Q904 | Q905 | Q906 | Q907 | Q908 | Q909 | Q910 | Q911 | Q912 | Q913 | Q914 | Q915 | Q916 | Q917 | Q918 | Q919 | Q920 | Q921 | Q922 | Q923 | Q924 | Q925 | Q926 | Q927 | Q928 | Q929 | Q930 | Q931 | Q932 | Q933 | Q934 | Q935 | Q936 | Q937 | Q938 | Q939 | Q940 | Q941 | Q942 | Q943 | Q944 | Q945 | Q946 | Q947 | Q948 | Q949 | Q950 | Q951 | Q952 | Q953 | Q954 | Q955 | Q956 | Q957 | Q958 | Q959 | Q960 | Q961 | Q962 | Q963 | Q964 | Q965 | Q966 | Q967 | Q968 | Q969 | Q970 | Q971 | Q972 | Q973 | Q974 | Q975 | Q976 | Q977 | Q978 | Q979 | Q980 | Q981 | Q982 | Q983 | Q984 | Q985 | Q986 | Q987 | Q988 | Q989 | Q990 | Q991 | Q992 | Q993 | Q994 | Q995 | Q996 | Q997 | Q998 | Q999 | Q1000 | Q1001 | Q1002 | Q1003 | Q1004 | Q1005 | Q1006 | Q1007 | Q1008 | Q1009 | Q1010 | Q1011 | Q1012 | Q1013 | Q1014 | Q1015 | Q1016 | Q1017 | Q1018 | Q1019 | Q1020 | Q1021 | Q1022 | Q1023 | Q1024 | Q1025 | Q1026 | Q1027 | Q1028 | Q1029 | Q1030 | Q1031 | Q1032 | Q1033 | Q1034 | Q1035 | Q1036 | Q1037 | Q1038 | Q1039 | Q1040 | Q1041 | Q1042 | Q1043 | Q1044 | Q1045 | Q1046 | Q1047 | Q1048 | Q1049 | Q1050 | Q1051 | Q1052 | Q1053 | Q1054 | Q1055 | Q1056 | Q1057 | Q1058 | Q1059 | Q1060 | Q1061 | Q1062 | Q1063 | Q1064 | Q1065 | Q1066 | Q1067 | Q1068 | Q1069 | Q1070 | Q1071 | Q1072 | Q1073 | Q1074 | Q1075 | Q1076 | Q1077 | Q1078 | Q1079 | Q1080 | Q1081 | Q1082 | Q1083 | Q1084 | Q1085 | Q1086 | Q1087 | Q1088 | Q1089 | Q1090 | Q1091 | Q1092 | Q1093 | Q1094 | Q1095 | Q1096 | Q1097 | Q1098 | Q1099 | Q1100 | Q1101 | Q1102 | Q1103 | Q1104 | Q1105 | Q1106 | Q1107 | Q1108 | Q1109 | Q1110 | Q1111 | Q1112 | Q1113 | Q1114 | Q1115 | Q1116 | Q1117 | Q1118 | Q1119 | Q1120 | Q1121 | Q1122 | Q1123 | Q1124 | Q1125 | Q1126 | Q1127 | Q1128 | Q1129 | Q1130 | Q1131 | Q1132 | Q1133 | Q1134 | Q1135 | Q1136 | Q1137 | Q1138 | Q1139 | Q1140 | Q1141 | Q1142 | Q1143 | Q1144 | Q1145 | Q1146 | Q1147 | Q1148 | Q1149 | Q1150 | Q1151 | Q1152 | Q1153 | Q1154 | Q1155 | Q1156 | Q1157 | Q1158 | Q1159 | Q1160 | Q1161 | Q1162 | Q1163 | Q1164 | Q1165 | Q1166 | Q1167 | Q1168 | Q1169 | Q1170 | Q1171 | Q1172 | Q1173 | Q1174 | Q1175 | Q1176 | Q1177 | Q1178 | Q1179 | Q1180 | Q1181 | Q1182 | Q1183 | Q1184 | Q1185 | Q1186 | Q1187 | Q1188 | Q1189 | Q1190 | Q1191 | Q1192 | Q1193 | Q1194 | Q1195 | Q1196 | Q1197 | Q1198 | Q1199 | Q1200 | Q1201 | Q1202 | Q1203 | Q1204 | Q1205 | Q1206 | Q1207 | Q1208 | Q1209 | Q1210 | Q1211 | Q1212 | Q1213 | Q1214 | Q1215 | Q1216 | Q1217 | Q1218 | Q1219 | Q1220 | Q1221 | Q1222 | Q1223 | Q1224 | Q1225 | Q1226 | Q1227 | Q1228 | Q1229 | Q1230 | Q1231 | Q1232 | Q1233 | Q1234 | Q1235 | Q1236 | Q1237 | Q1238 | Q1239 | Q1240 | Q1241 | Q1242 | Q1243 | Q1244 | Q1245 | Q1246 | Q1247 | Q1248 | Q1249 | Q1250 | Q1251 | Q1252 | Q1253 | Q1254 | Q1255 | Q1256 | Q1257 | Q1258 | Q1259 | Q1260 | Q1261 | Q1262 | Q1263 | Q1264 | Q1265 | Q1266 | Q1267 | Q1268 | Q1269 | Q1270 | Q1271 | Q1272 | Q1273 | Q1274 | Q1275 | Q1276 | Q1277 | Q1278 | Q1279 | Q1280 | Q1281 | Q1282 | Q1283 | Q1284 | Q1285 | Q1286 | Q1287 | Q1288 | Q1289 | Q1290 | Q1291 | Q1292 | Q1293 | Q1294 | Q1295 | Q1296 | Q1297 | Q1298 | Q1299 | Q1300 | Q1301 | Q1302 | Q1303 | Q1304 | Q1305 | Q1306 | Q1307 | Q1308 | Q1309 | Q1310 | Q1311 | Q1312 | Q1313 | Q1314 | Q1315 | Q1316 | Q1317 | Q1318 | Q1319 | Q1320 | Q1321 | Q1322 | Q1323 | Q1324 | Q1325 | Q1326 | Q1327 | Q1328 | Q1329 | Q1330 | Q1331 | Q1332 | Q1333 | Q1334 | Q1335 | Q1336 | Q1337 | Q1338 | Q1339 | Q1340 | Q1341 | Q1342 | Q1343 | Q1344 | Q1345 | Q1346 | Q1347 | Q1348 |
|------|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|----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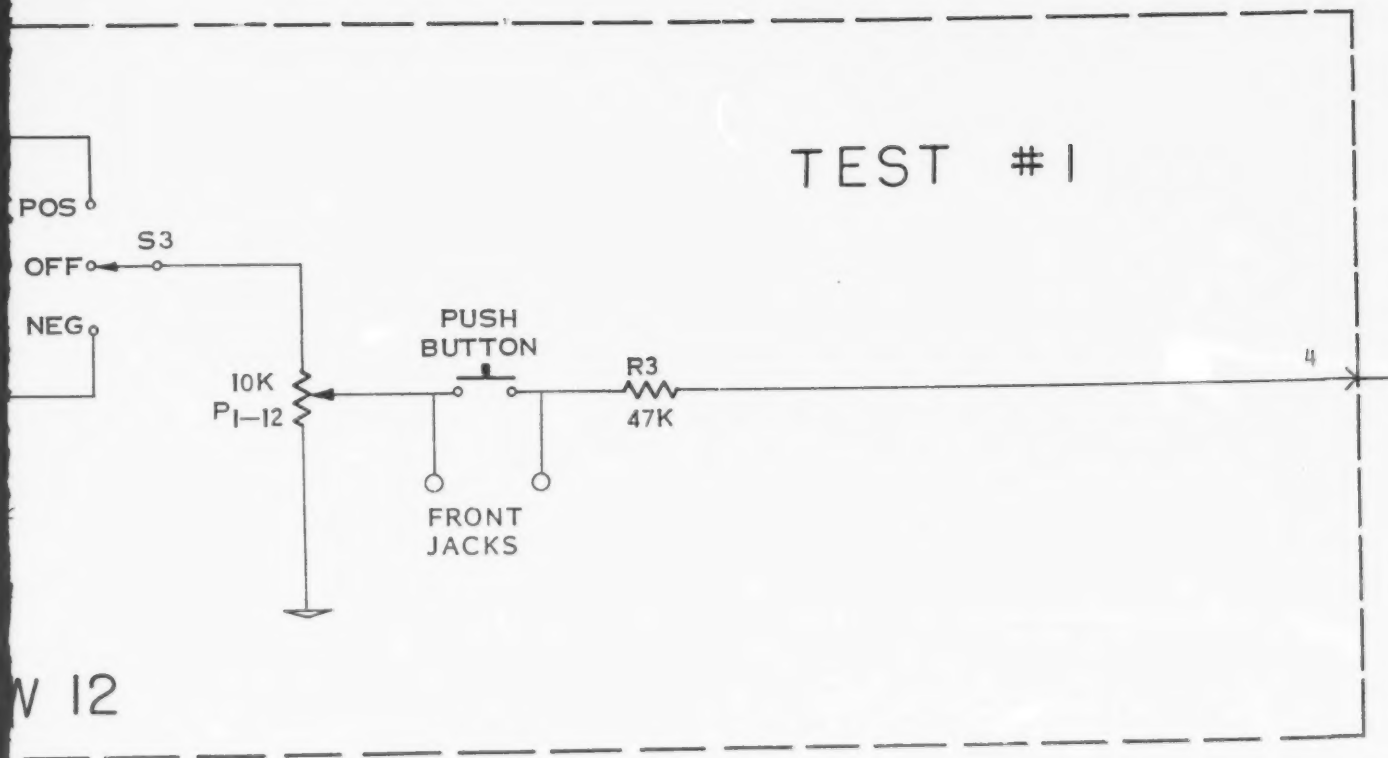
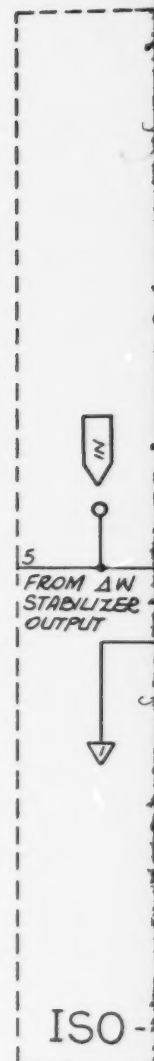
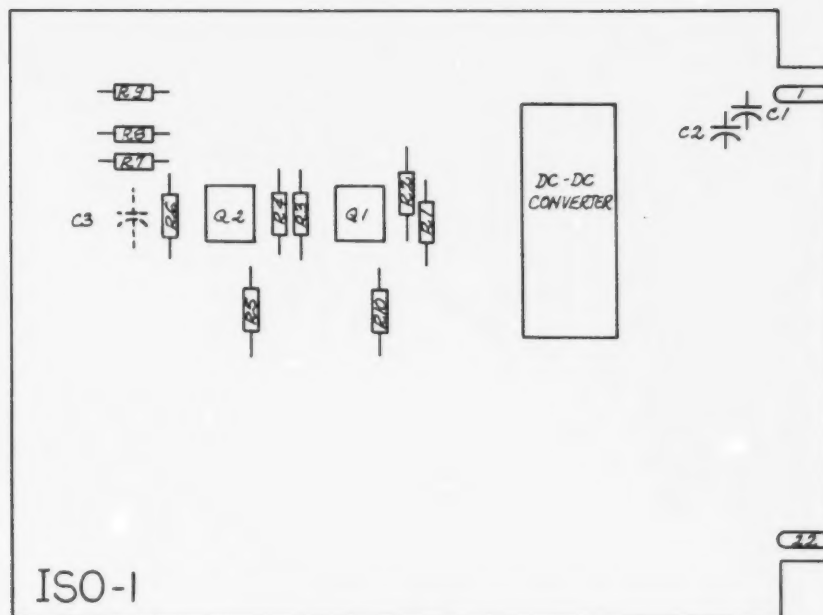


FIGURE 4-14  
 BRUCE 'A' NGS -  $\Delta\omega$  STABILIZER  
 TEST NO.1 CARD - SCHEMATIC DIAGRAM



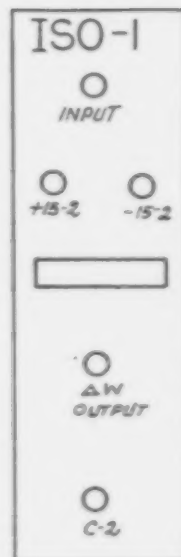
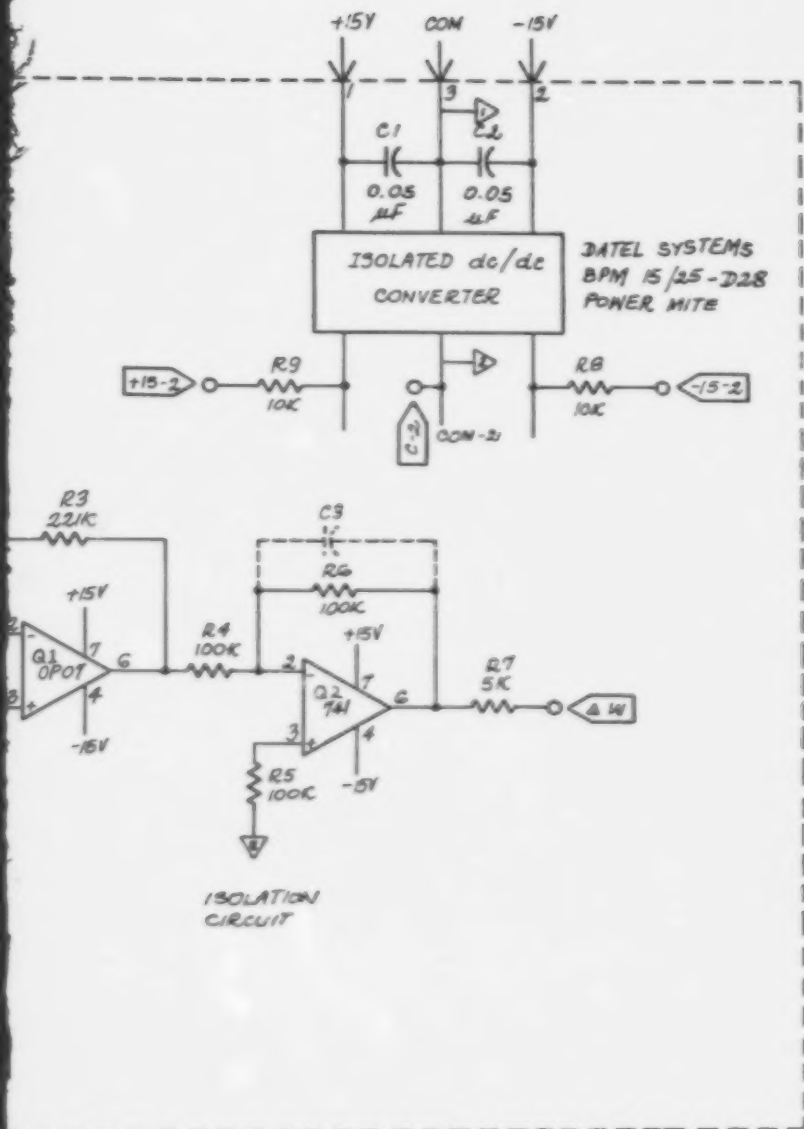
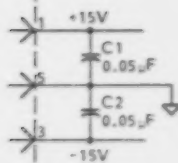
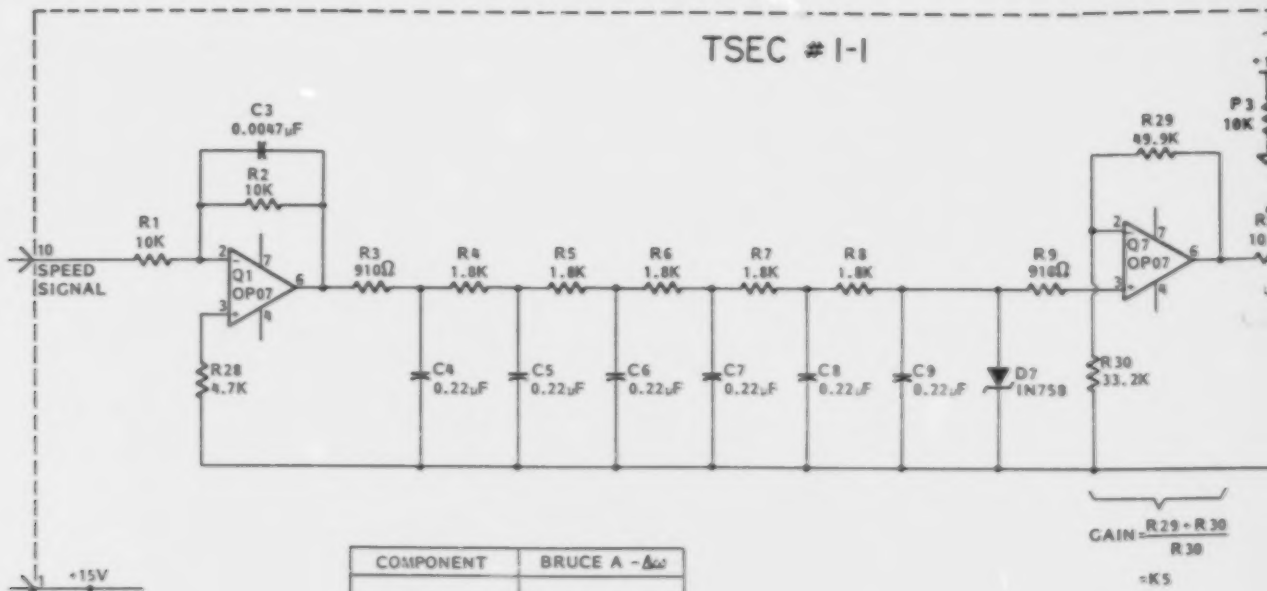
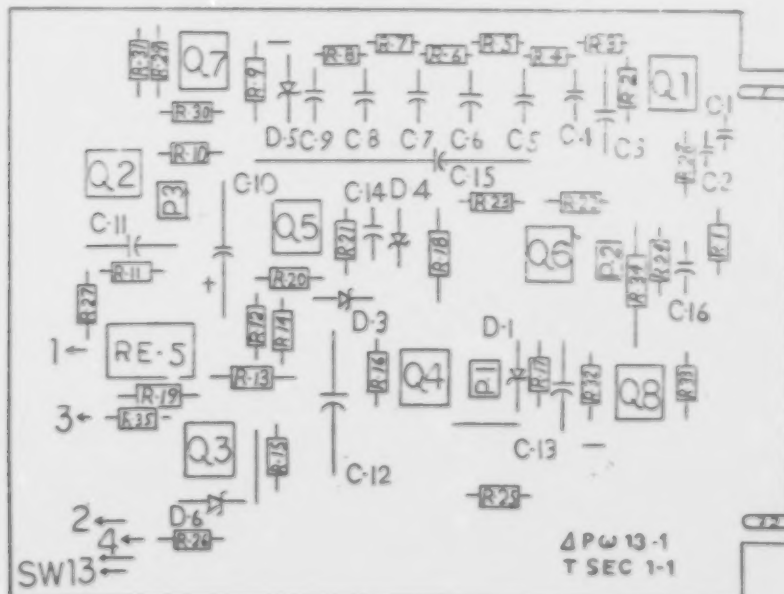


FIGURE 4-15  
ISOLATOR CARD FOR  
THE BRUCE 'A'  $\Delta\omega$  STABILIZERS



| COMPONENT | BRUCE A - Δω |
|-----------|--------------|
| R11       | 124K         |
| R15       | 169K         |
| R17       | 30.1K        |
| R19       | 22.1K        |
| R21       | 100 K        |
| R24       | 100 K        |
| D1        | 1N5236B      |
| D2        | SHORT        |
| D5        | SHORT        |
| D6        | 1N5231B      |

TSEC#1-1-ΔPω13-1



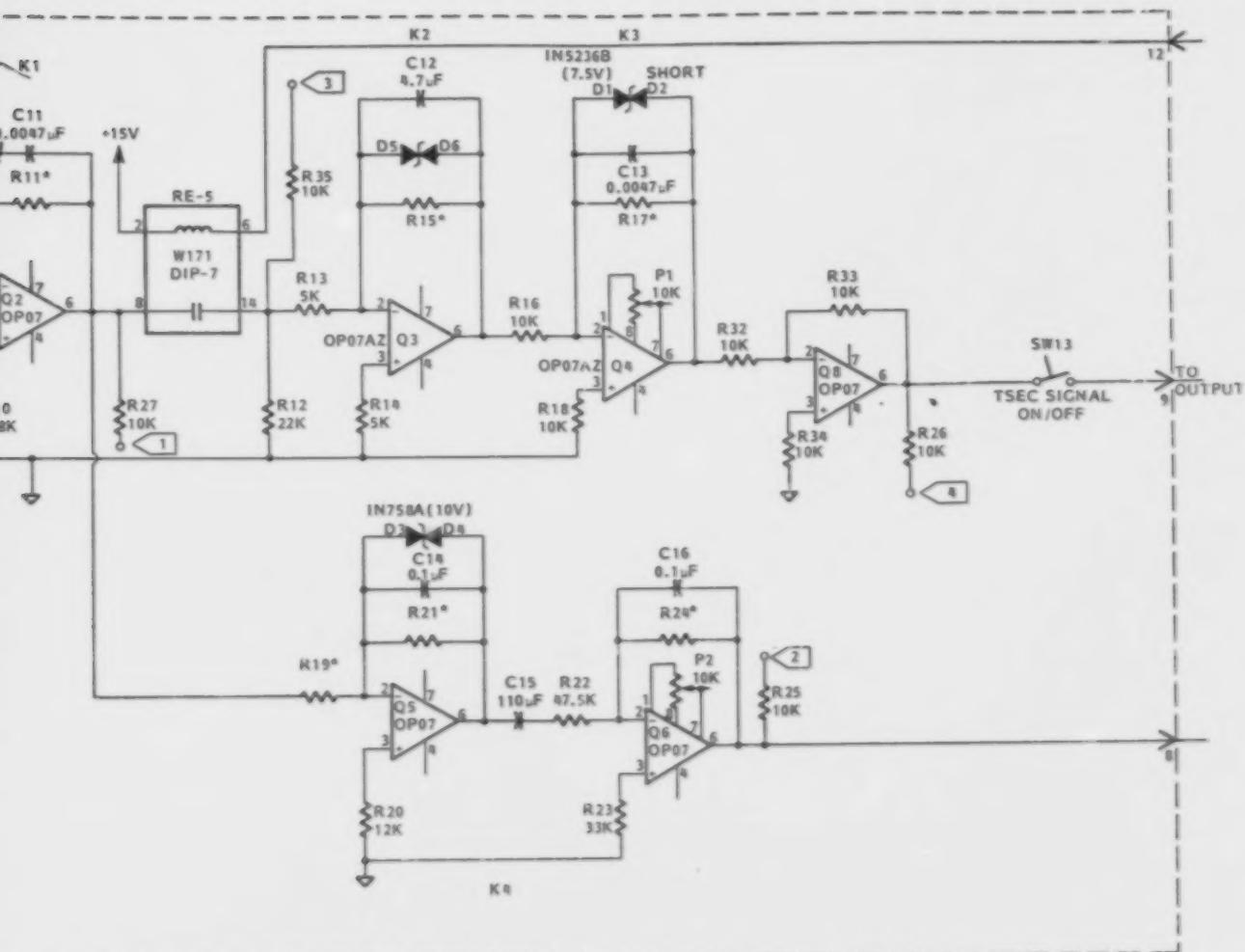
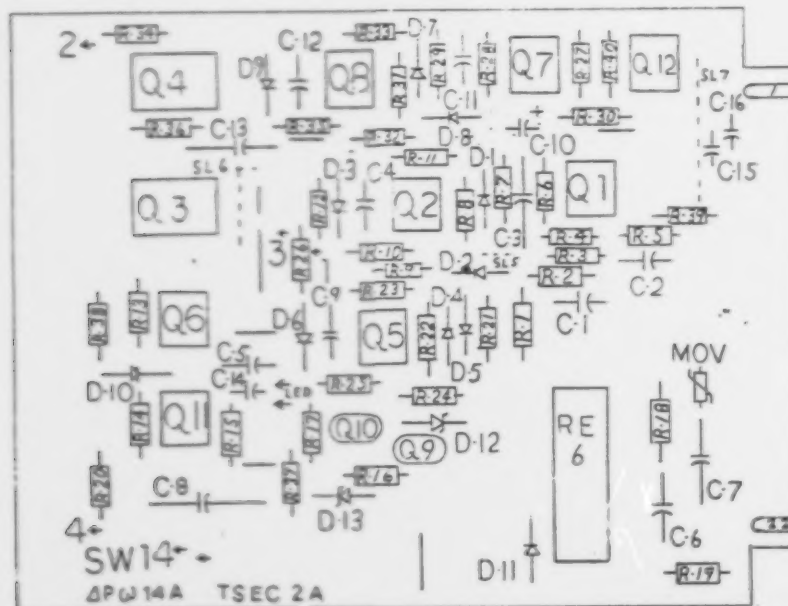
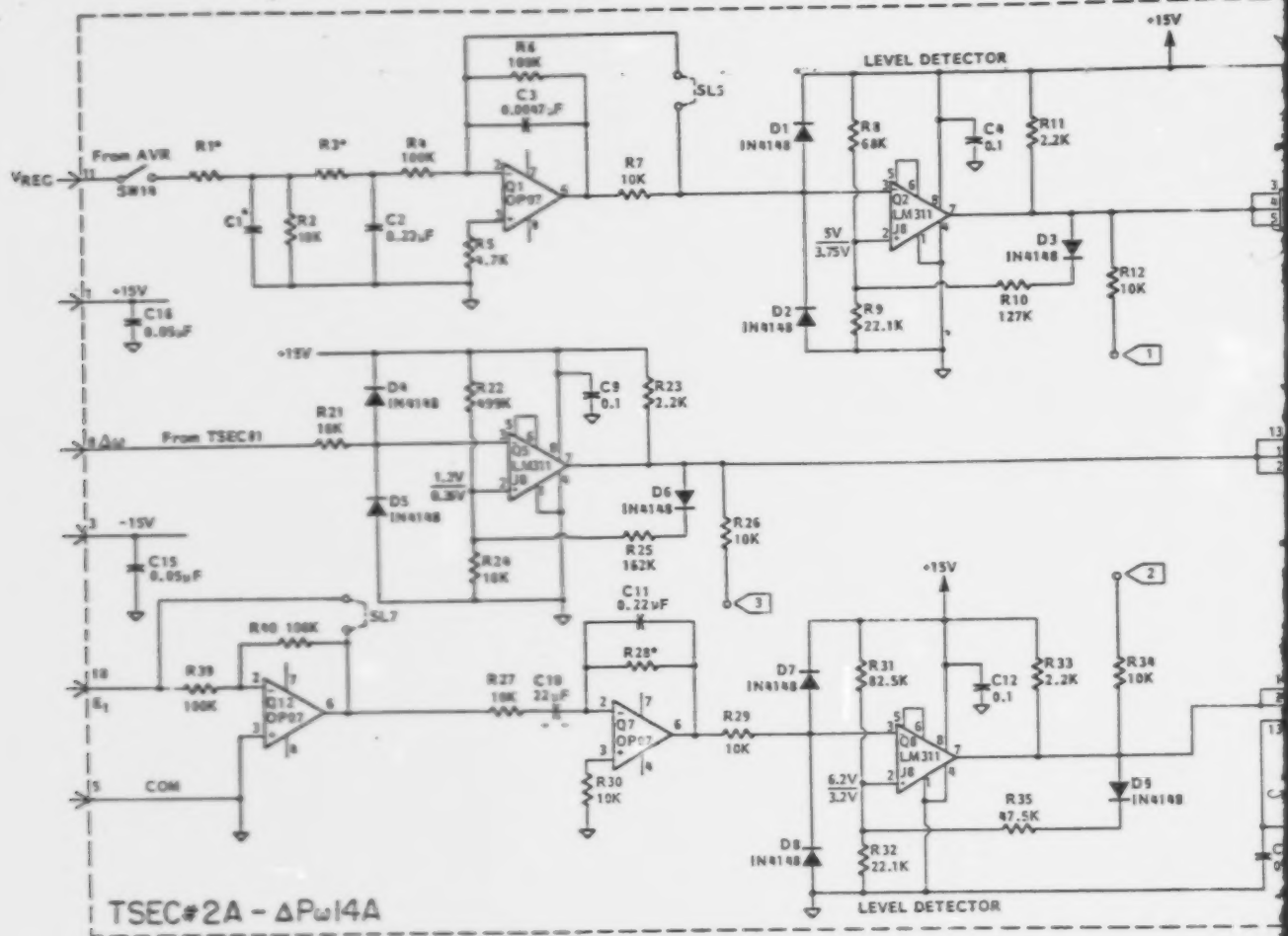


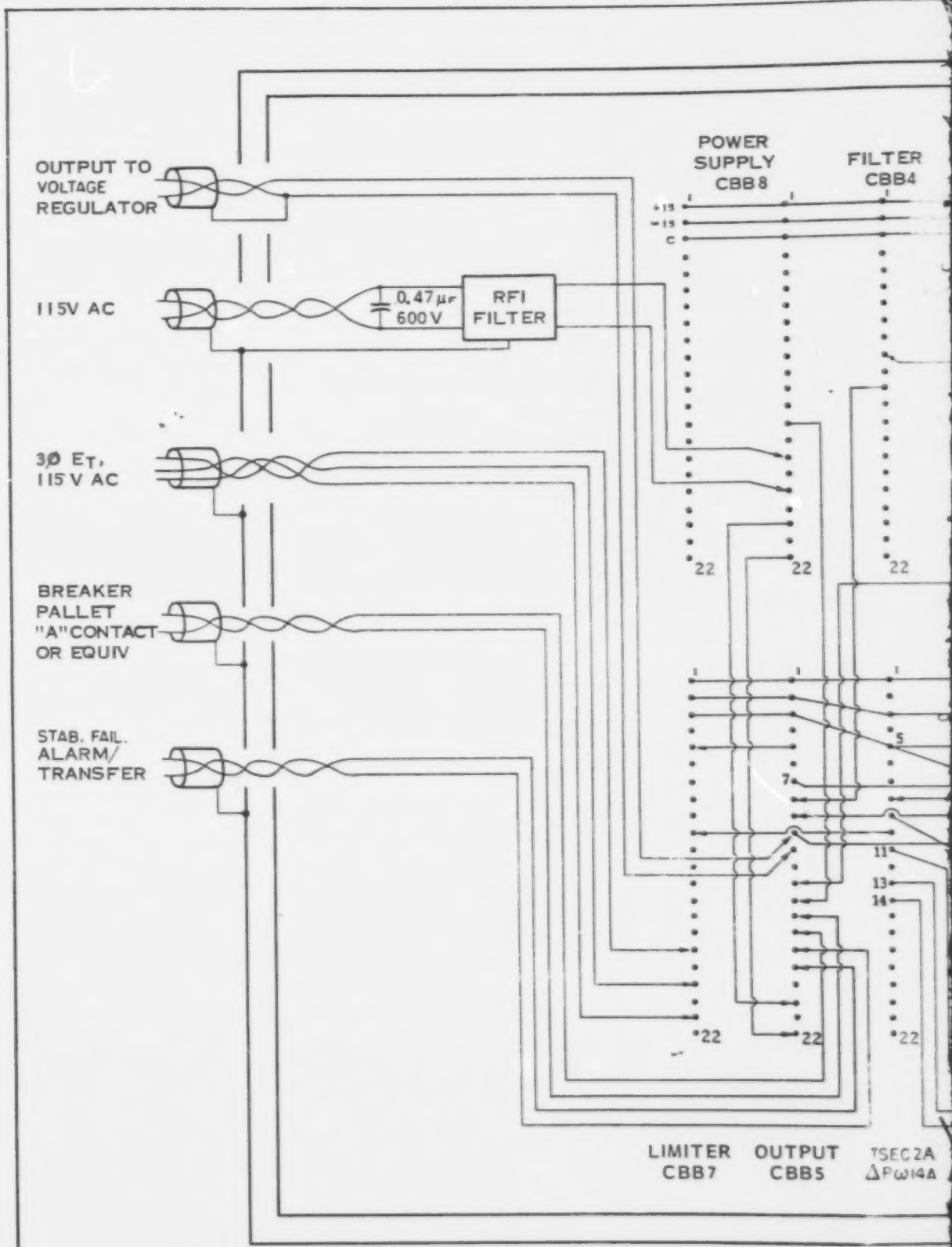
FIGURE 4-16

BRUCE 'A'  $\Delta\omega$  STABILIZER  
TSEC 1-1 CARD -  $\Delta\omega$  13-1, REVISED FEBRUARY 1984









NOTE: - FOR EXTERNAL CONNECTIONS SEE STATION DRAWING  
NO NK21-DE-64122-86

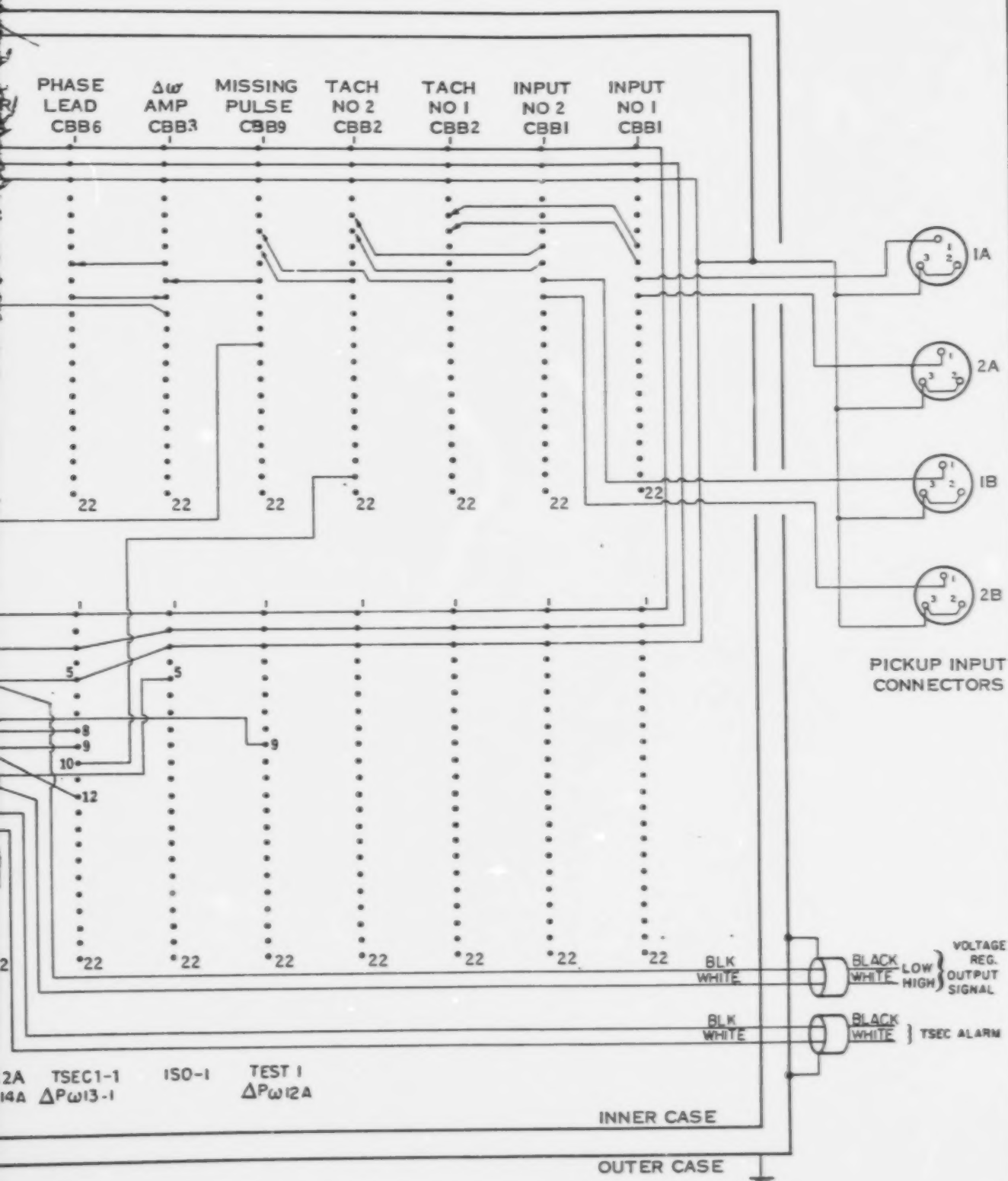


FIGURE 4-18

DELTA-OMEGA STABILIZER CARD INTERCONNECTION AND CASE WIRING DIAGRAM  
BRUCE "A" GS --REVISED APRIL 84

27856-RD-R1

|             |             |            |            |                  |                        |               |            |              |         |
|-------------|-------------|------------|------------|------------------|------------------------|---------------|------------|--------------|---------|
| Input<br>#1 | Input<br>#2 | Tach<br>#1 | Tach<br>#2 | Missing<br>Pulse | $\Delta\omega$<br>Amp. | Phase<br>Lead | Filter     | Power Supply |         |
| Spare       | Spare       | Spare      | Spare      | TEST 1           | ISO-1                  | TSEC<br>1-1   | TSEC<br>2A | Output       | Limiter |

FIGURE 4-19  
 $\Delta\omega$  STABILIZER - CARD LAYOUT WITH TEST CARDS - FRONT VIEW  
 BRUCE 'A' GS  
 REVISED APRIL 84 .

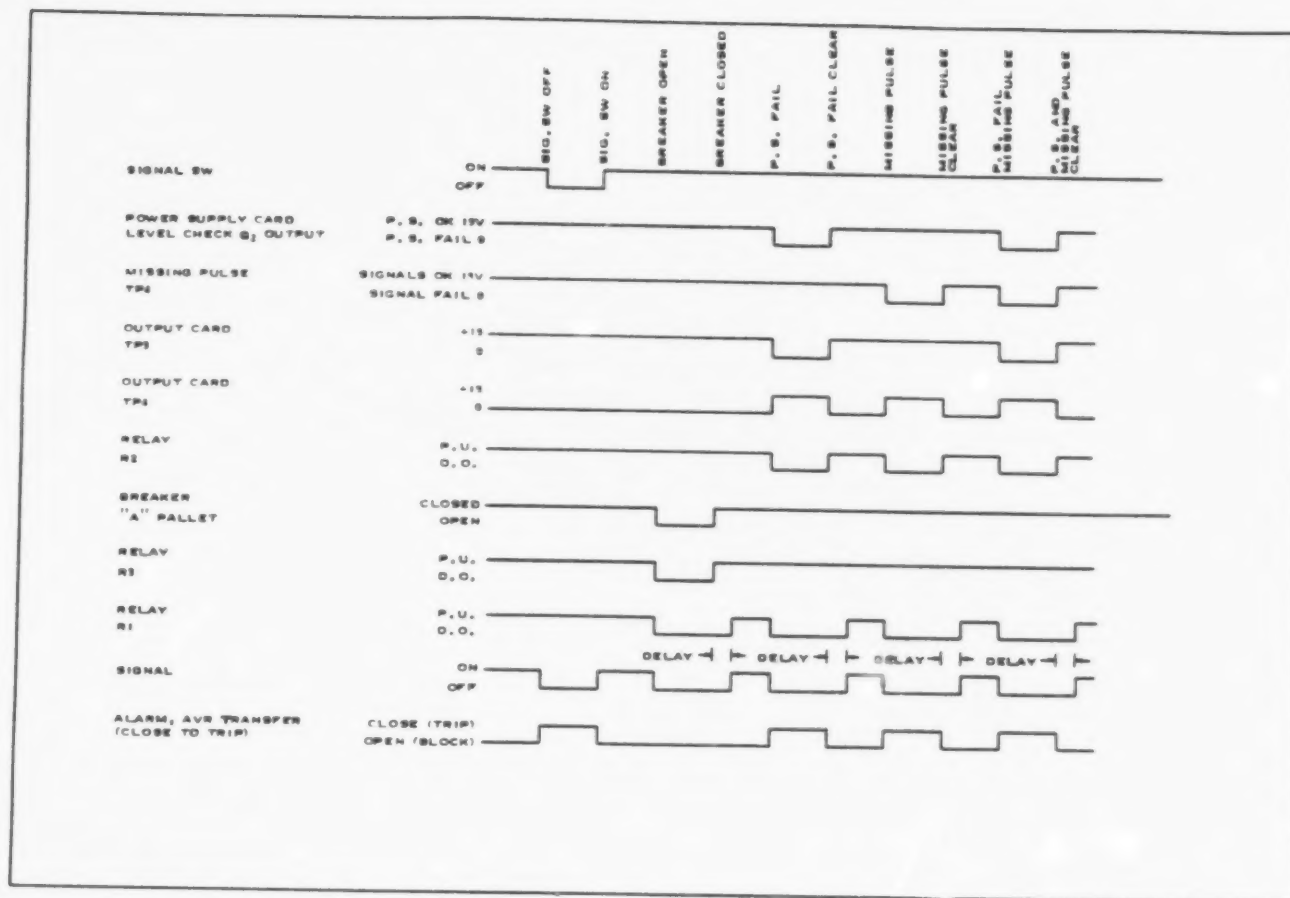


FIGURE 4-20  
LOGIC FOR BRUCE "A" CS  
DELTA-OMEGA STABILIZER PROTECTION CIRCUITS

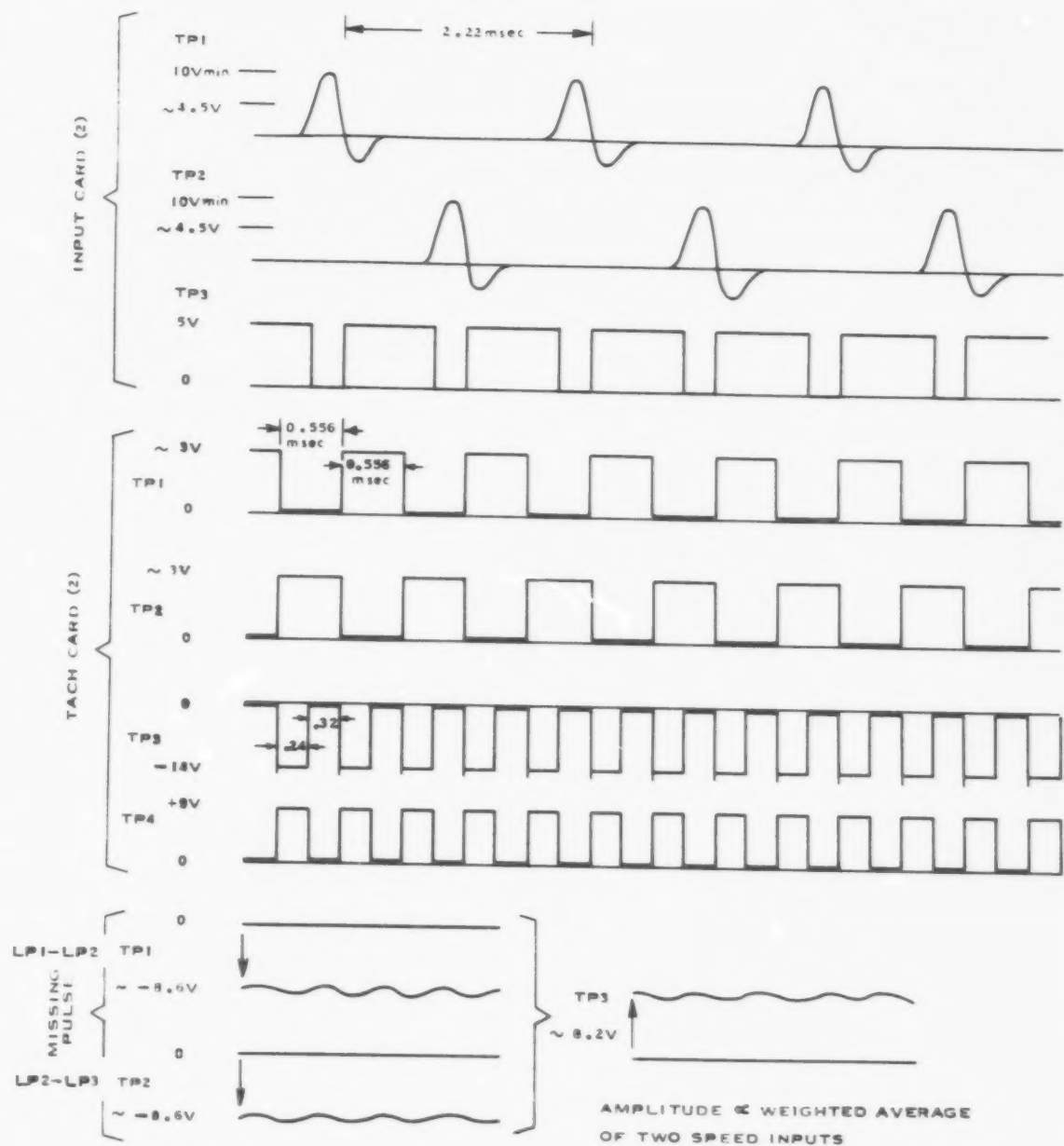
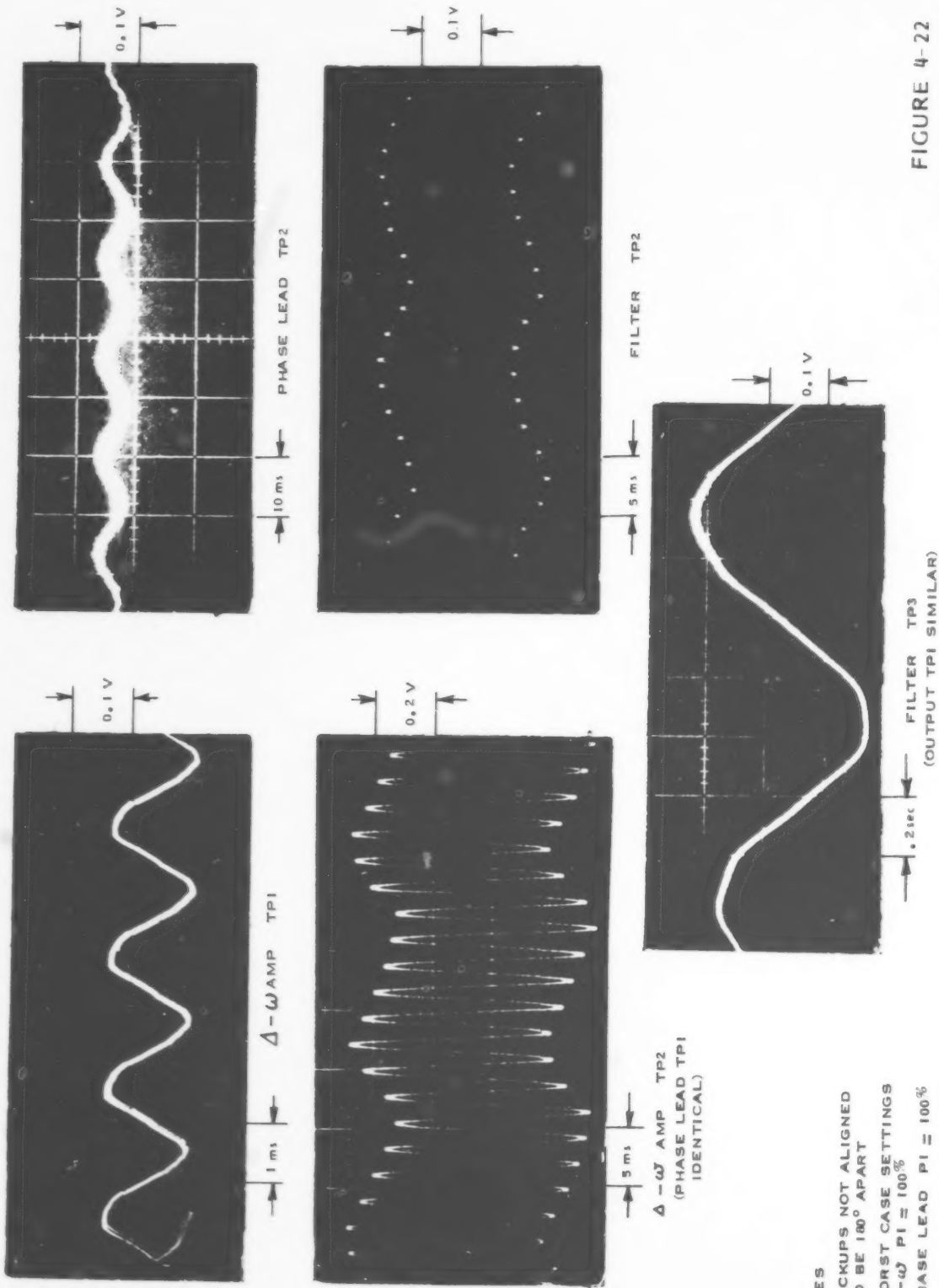


FIGURE 4-21  
 BRUCE GS - DELTA OMEGA  
 1800 RPM - 15 SLOTS - TWO PICKUPS PER WHEEL - TWO SPEED WHEELS  
 TYPICAL WAVEFORMS





- NOTES
- PICKUPS NOT ALIGNED TO BE 180° APART
  - WORST CASE SETTINGS
  - $\Delta - \omega$  PI = 100%
  - PHASE LEAD PI = 100%
  - P2 = 100%

FIGURE 4-22  
TYPICAL WAVEFORMS - BRUCE "A" GS  
DELTA-OMEGA STABILIZER

## SECTION 5

### INSTALLATION, COMMISSIONING, MAINTENANCE, DYNAMIC TESTING AND SPECIFICATIONS

#### 5.0 GENERAL

The need for a stabilizer on a given generating unit is generally determined early in the design stages of the station. The stabilizer is installed either by the excitation system supplier or by Ontario Hydro as per the information contained in the installation standard/11/ SCI No 908-42200-01, "Interface Requirements for the Power System Stabilizer", issued in April 1979 by the Design and Development Division. Details provided here should be used in conjunction with the installation standard.

The initial commissioning of most power system stabilizers is done by Research Division staff.

#### 5.1 Mechanical Details

The  $\Delta\omega$  stabilizer is housed in a double walled, two-tier metal cabinet with outside dimensions shown in Figure 5-1. The cabinet can be rack or wall mounted as shown in Figure 5-2. Metal brackets are used in either case to support the weight and to make it easier to mount or remove the cabinet.

The speed signal connectors are mounted on the left-hand side of the case if the stabilizer is to be wall mounted. If it is rack or flush mounted, the connectors are at the rear.

All other input and output leads exit through the right end of the case (viewed from the front).

A ventilation opening over the power supply module provides sufficient air movement to maintain a normal operating temperature inside the case. A clearance of at least 3 cm must be provided immediately above the cabinet for ventilation purposes.

#### 5.2 Speed Signal Pickup Mounting and Adjustment

Four electromagnetic pickups, type 3010AN, manufactured by Electro Magnetic Sensors Corporation, are used to sense the speed of the generator shaft. The pickups are in two sets, one

set located between LP1 and LP2 and the other set between LP2 and LP3. The pickups of each set must be mounted  $180^\circ \pm 2^\circ$  apart around the shaft circumference to provide a symmetrical pulse train.

The pickup gapping adjustment can be done as per the instructions on Figure 5-3. A gap of 1.25 mm ( $\approx 0.05$  inch) between the pickup face and the toothed wheel will result in a minimum speed signal amplitude of 12 V zero-to-peak.

### 5.3 Electrical Details

Power system stabilizers work with very low-level electrical signals in an electrically noisy environment. It is essential that proper wiring techniques be used to provide adequate signal shielding and to ensure that the stabilizer common is tied to the excitation system common at only one point. In the  $\Delta\omega$  stabilizer the tie between the two commons is done with the two-conductor output signal lead.

The speed pickups wiring is done as per Figure 5-4. A ground anywhere along the pickup wiring could result in a severe noise problem and care must be exercised to avoid weak spots in the wiring. The inner and outer shields must be connected exactly as shown in the diagram to avoid interference problems.

The inner stabilizer case is tied to the electronic circuit common and is isolated from the outer case. However, for some generators, the exciter electronic circuits common may be tied to the station ground, in which case the inner and outer case are effectively tied together through the exciter. In all installations, the outer stabilizer case is solidly connected to the station ground through the grounding lug provided.

In addition to the speed signal cables, the following input/output cables are provided, some marked as optional:

1. Stabilizer Malfunction Annunciation
2. Stabilizer Output Signal
3. 115 V ac power
4. Voltage Regulator Output Signal (optional)
5. TSEC Operation Annunciation (optional)
6. 3-Phase Terminal Voltage
7. Spare (for use in future testing program).

Cables for 1, 3, 6 and 7 are single shielded and the shield is tied to the outer stabilizer case. The remote end of the shield must be tied to the station ground.

Cables for 2 and 4 are double-shielded with the inner shield tied to the electronic circuit common and the outer shield tied to the outer case. At the remote end of these cables the inner shield is left floating and the outer shield is solidly grounded. It is permissible to leave both shields floating at the remote end if the termination is in the same cubicle. However, the two shields must not be tied together.

#### 5.4 Connection of Annunciation Outputs

The stabilizer malfunction annunciation contact can be used for either annunciation only or for annunciation and transfer of AVR control.

The TSEC operation annunciation contact is intended only for annunciation and its use is optional. The contact closes whenever the TSEC circuit is called upon to operate. It does not indicate a TSEC failure (except for a limited number of failures which would cause the final output stages of the TSEC to malfunction).

The ratings of both contacts is given in Section 5.9. Damage to the relays will result if these ratings are exceeded.

#### 5.5 Commissioning

The initial in-service commissioning of all  $\Delta\omega$  stabilizers is performed by staff of the Research Division. Following a major unit shutdown it may be necessary to check that the stabilizer is still operational and this check would be performed by station personnel. The procedure outlined below, along with the information provided in other parts of this Manual, should be used.

High impedance (greater than 1 M $\Omega$ ), ungrounded instruments should be used for all on-line measurements. If coaxial leads are used with recording equipment, a high resistance (10 k or greater) should be inserted in series with the test point to prevent capacitive loading of operational amplifiers.

The following steps should be followed in commissioning the  $\Delta\omega$  stabilizers.

1. Check that the electromagnetic pickups are installed and adjusted as described in Section 5.2.

2. Check that all wiring conforms to Figure 4-18 and the station drawings listed in Section 5.10.
3. Check that the stabilizer inner case is not grounded.

If the generator is shut down, many of the stabilizer checks can still be performed by inserting a 900 Hz sine wave of about 6 V zero-to-peak amplitude into TP1 or TP2 of both input cards simultaneously. By appropriately frequency modulating this signal, stabilizer transfer functions can be checked.

The procedures which follow assume that the generator is running at speed, but the stabilizer is not in service (alternate voltage regulator controlling).

4. Check power supply voltages.
5. Check the four pickup signals (TP1 and TP2 of the two input cards). They should resemble the waveforms shown in Figure 4-21 and should have zero-to-peak amplitudes of 10 V or more.
6. Check that the remainder of the input and tach card waveforms are as shown in Figure 4-21.
7. Each tach card produces an output voltage proportional to speed (~8.2 V at rated speed). These two voltages can be monitored at TP1 and TP2 of the missing pulse card.
8. These two signals are combined to form a single speed signal (~8.2 V at rated speed) which can be monitored at TP3 of the missing pulse card. These signals (TP1, TP2 and TP3 of the missing pulse card) should appear as clean dc quantities. Variations will be very small compared with the dc values.
9. The signal is then passed through two "washout" functions (high pass filters) with time constants of 4.7 and 1.5 s. The dc component (corresponding to steady-state speed) is blocked and only speed changes are amplified further. At this point, two "noise" components become evident. One is a 450 Hz component due to the pickups not being located exactly 180° apart, and the other is a 60 Hz component due to cumulative slot machine errors. In Figure 4-22, these noise components are shown for "worst case" stabilizer settings. Check that the 450 Hz and 60 Hz components at the  $\Delta\omega$  amp TP1 and TP2 are lower than those shown in Figure 4-22 for the existing stabilizer settings.

10. Check that 450 Hz and 60 Hz noise components at TP1 of phase lead card TP2 of filter card are not more than those shown in Figure 4-22.
11. Check the signal at TP3 of the filter card. It should be a clean signal varying about zero with frequency components at about 0.8 Hz and possibly some at about 4 Hz. The 0.8 Hz component is the machine-system mode of oscillation for which damping is required and the 4 Hz component (if visible) is due to the peak in the filter characteristic. The signal should resemble that shown in Figure 4-22, although the amplitude will be different with different stabilizer parameters and system conditions.

The signal should be similar at TP1 of the output card, and, for conditions where the stabilizer is connected to the regulator the signal at TP2 will be identical.
12. To check that the signal path is complete, the dynamic test procedure of Section 5.8 can be used.
13. The only convenient method of checking stabilizer settings is by means of response testing. If settings are suspect, Research Division should be contacted. Periodic testing using the procedure of Section 5.8 should ensure that a healthy stabilizer is in service.
14. Switching logic can be checked with the aid of Figure 4-20. It should be noted that one of the circuits on the output card, which includes the breaker pallet status detection, is isolated from the remainder of the stabilizer circuitry.

#### 5.6 Troubleshooting

Troubleshooting a faulty stabilizer requires a good understanding of all circuit operations. Section 4 provides detailed descriptions of all the circuits and typical waveforms are provided for the test points. A combination of test point measurements and card interchange with the spare cards provided should help in locating the trouble.

An audio oscillator set at the frequency of the speed signal can be used to simulate the speed signal.



When interchanging cards it is essential that the replacement cards have identical component values and settings as the cards being replaced. An error in setting or component value will have a serious adverse effect on the stabilizer performance and could lead to dynamic instability.

If the problem proves too elusive, the complete stabilizer can be put through the manufacturing test procedure, details of which are available from the Research Division.

#### 5.7 Biennial Maintenance

The  $\Delta\omega$  stabilizer uses solid-state circuitry throughout with no moving parts. Consequently, a minimum amount of maintenance is required. The dynamic test procedure referred to in Section 5.8 will essentially verify that most of the circuits are set correctly and perform as expected. The steps outlined below can be used in addition to the dynamic test procedures.

1. With the unit at speed, check the signal amplitudes at TP1 and TP2 of both Tach cards.

The remaining checks may be performed with the unit on line on AVR "B" control or with the unit shut down. If the unit is shut down, set up a signal generator to produce a 900 Hz sine wave with an amplitude of about 6 V (zero-to-peak) into TP1 of both input cards. Stabilizer waveforms should now resemble those of Figure 4-21 (except for the input signals).

2. If the unit is shut down, temporarily jumper the breaker pallet logic input to simulate the unit synchronized condition.
3. Observe TP2 of the output card. With the unit on line, speed variations at about 0.8 Hz should appear at this test point. If the unit is shut down, the random variations of the signal generator frequency will be evident at this point.
4. Check that the stabilizer output signal appears on the voltage regulator output signal.



If the unit is on-line transfer AVR control to channel 'B' and defeat the AVR 'A' to AVR 'B' transfer.

5. Refer to Figure 4-20. Turn off signal switch. Check that the stabilizing signal disappears and the alarm/transfer contact closes. Turn signal switch on.
6. If the unit is running, momentarily short TP1 of one input card to common and check that the stabilizing signal is removed and the alarm/transfer contact closes. Repeat with TP1 and TP2 of the other input card.

If the unit is shut down, remove the signal input to TP1 of the input card. Check that the stabilizing signal is removed and alarm/transfer contact closes. Replace this input and repeat removing the TP1 input to the other input card.

7. Restore the system to its pre-test state.

#### 5.8 Dynamic Testing of Exciter and Stabilizer Performance

In 1980 a detailed test procedure was developed to verify the dynamic performance of power system stabilizers and excitation systems. The procedure is described in Research Report 80-294-K issued September 9, 1980, "Detailed Procedure for Dynamic Testing of Excitation Systems and Power System Stabilizers". The pertinent details of this procedure, as it applies to Bruce 'A' are reproduced here.

The procedure requires the use of a hot pen or ink recorder equipped with four medium gain channels. All other equipment to apply the step disturbance and interface the recording equipment to the signals is provided as an integral part of stabilizers.

##### 5.8.1 Determination of a Testing Policy

Prior to any tests being performed, a general policy on when the tests are to be done must be established. This policy is the responsibility of station personnel in cooperation with System Control, System Performance and other concerned parties. The tests could be done every six months during off-peak hours, or once a year prior to a unit shutdown or whenever convenient. The nature of the tests is such that they could be performed at almost any time without affecting the system. Transferring to channel B AVR and testing its response may be scheduled immediately prior to a unit shutdown to take care of the possibility that the transfer scheme may fail.

The personnel designated to perform the tests should have some basic knowledge of the stabilizer and excitation system to appreciate the nature of the tests and the care to be exercised. Assessing the results obtained on the recorder and comparing them to reference traces requires some knowledge of normal responses for the quantities recorded and some understanding of damping on control systems. Personnel normally charged with the commissioning and maintenance of exciters and stabilizers are in a position to perform these tests.

#### 5.8.2 Preliminary Work

The following work must be performed prior to connecting the recording equipment to the stabilizer:

- a) Coordinate the testing schedule with the unit operators. Testing must be done at a loading greater than 75% of rated. Determine the appropriate time of day at which the tests are to be performed. Ensure that all groups which should be notified are aware that the tests will be performed. If contingency measures are to be taken, ensure that they have been taken.
- b) Through discussions with the unit/station operators and visual inspection of the excitation system and stabilizer, determine the apparent status of the system. Check for targets, blocking switches in incorrect positions, restrictions on the system, abnormal behaviour, tracking between regulators and any other signs which could indicate the health of the system. If everything is okay, testing may proceed. Tests must not proceed if there is an obvious fault or limitation on the system which could adversely affect the system.
- c) Calibrate the recorder and check its overall operation. Check the quality of leads, possible damage to the amplifiers, noise in the channels, short circuits at the inputs etc. Leads must be clearly identified to avoid connection errors.

#### 5.8.3 Performing the Test

With the requirements of Section 5.8.2 satisfied, it is now possible to proceed with the test. The test requires monitoring four key quantities: terminal voltage, field voltage, electrical power and stabilizer output. In Bruce 'A' NGS, each exciter has two AVR channels, with the 'A' channel normally in service.

The  $\Delta\omega$  stabilizer is connected to the 'A' channel and a  $\Delta P\omega$  is connected to the 'B' channel. In 1982/83 dynamic test facilities were added to both stabilizers. The  $\Delta\omega$  stabilizer was equipped with an isolating circuit for the output signal and a step disturbance generator. The  $\Delta P\omega$  was equipped with isolating circuits for the generator terminal voltage, field voltage, electrical power and  $\Delta P\omega$  stabilizer output and a step disturbance generator.

Whether the tests are performed with the 'A' or 'B' regulating channel in service the first three recorder channels will always be connected to the  $\Delta P\omega$  isolating circuits. The stabilizer output signal will be from the appropriate stabilizer and the step disturbance will be applied through the stabilizer which is in service at the time.

The terminal voltage signal is measured on TP- $E_t$  of the  $\Delta P\omega$  stabilizer with a floating dc voltmeter. This signal should be approximately 6.5 V and it should be related to the primary terminal voltage by obtaining  $E_t$ -primary from the unit operators.

TP- $E_t$  signal \_\_\_\_\_ V dc = \_\_\_\_\_ kV primary.

The  $E_t$  BIAS and RANGE potentiometers on Test 3 card are adjusted to produce a zero volt signal on TP- $\Delta E_t$ . To adjust these two potentiometers, connect a voltmeter to TP- $\Delta E_t$ . Set the ten-turn  $E_t$  BIAS potentiometer to 5.0/10. Now, if the signal on TP- $\Delta E_t$  is positive, turn the RANGE potentiometer clockwise until the signal on the voltmeter is approximately zero. The BIAS potentiometer can then be used to fine-tune the biasing. Note that with a unit on line, the terminal voltage fluctuates constantly and the signal on TP- $\Delta E_t$  will have a small "noise" component.

With the application of a step disturbance, changes in  $E_t$  are measured in TP- $\Delta E_t$  as per:

$$\Delta E_t \text{ in } \% = \frac{\text{TP-}\Delta E_t \text{ signal (V dc)}}{\text{TP-}E_t \text{ signal} \times 20} \times 100\%$$

The electrical power signal is calibrated in much the same way. The signal on TP- $P_e$  is measured and related to the existing loading on the unit. The signal on TP- $P_e$  should be:

$$\text{TP-P}_e \text{ signal} = \frac{\text{MW} \times 10^6}{\text{CT} \times \text{PT}} \times 0.1 \times 10^{-3} \times 31.9 = \frac{\text{MW} \times 3190}{\text{CT} \times \text{PT}} \text{ V dc}$$

$$\text{TP-P}_e \text{ signal} \text{ _____ (V dc)} = \text{_____ MW (existing loading)}$$

The  $P_e$  BIAS and RANGE potentiometers on Test 3 card are adjusted to produce a zero volt signal on  $\text{TP-}\Delta P_e$ . Connect a voltmeter to  $\text{TP-}\Delta P_e$ . Set the ten-turn  $P_e$  BIAS potentiometer to 5.0/10. Now if the signal on  $\text{TP-}\Delta P_e$  is positive turn the RANGE potentiometer clockwise until the signal is approximately zero. The BIAS potentiometer can then be used to fine-tune the biasing.

With the application of a step disturbance,  $P_e$  will swing and the peak of the swing, in megawatts, is calculated from:

$$\Delta P_e \text{ in MW} = \frac{\text{TP-}\Delta P_e \text{ signal (V peak)}}{\text{TP-P}_e \text{ signal} \times 20 \text{ (V dc)}} \times \text{MW loading}$$

The field voltage signal is measured on  $\text{TP-E}_f$ . The field voltage signal on  $\text{TP-E}_f$  should be:

$$\text{TP-E}_f = 0.0071 E_{f\text{-pri}} \text{ V dc}$$

The stabilizer signal is measured on the appropriate test point, either  $\text{TP-}\Delta \omega$  on the 150-1 card of the  $\Delta \omega$  stabilizer or  $\text{TP-}\Delta P_\omega$  of the  $\Delta P_\omega$  stabilizer. The stabilizer signal should be less than 100 mV with no disturbance applied.

The recorder is then connected to the four test points:  $\Delta E_t$ ,  $E_f$ ,  $\Delta P_e$  and  $\text{TP-}\Delta \omega$  or  $\text{TP-}\Delta P_\omega$ . The zeros of  $\Delta E_t$  and  $\Delta P_e$  can be precisely adjusted to match the recorder zeros (no trace offset).

A remote push button connected to the front jacks of TEST 1 card or the card-mounted PB can be used to apply the disturbance. The switch on this card is moved to the POS position and potentiometer P1 on this card is gradually increased until the disturbance, as measured by  $\Delta E_t$ , has the desired amplitude. The recorder traces must be observed closely at all times to detect any undesirable effects. A change of 1% in  $E_t$  is sufficient to determine the effectiveness of the excitation system and stabilizer. A good quality record at a recorder speed identical



to previous records is taken and kept as the system "signature" for that particular day and particular system conditions. The loop gain is measured, as per Section 5.8.4 and the record is compared to reference traces obtained previously with and without the stabilizer. Notes are made of the station conditions at the time of test: units in service, bus voltage, lines in service, total station load, etc.

Figure 5-5 shows a typical record obtained using a similar test procedure. The record with the stabilizer out of service would not normally be obtained every time this test procedure is used as it requires System Control approval to remove the stabilizer from service (turning the gain to zero).

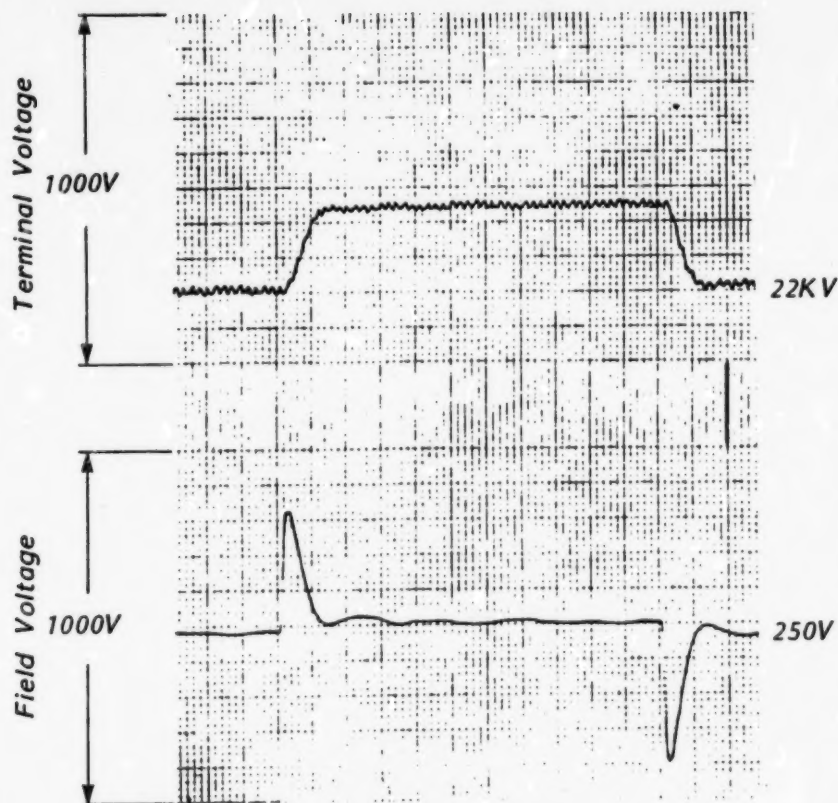
#### 5.8.4 Measurement of Voltage Regulator Loop Gain

The voltage regulator loop gain of static exciters with no transient gain reduction (most exciters equipped with stabilizers) can be measured directly from the test record obtained by scaling the terminal voltage and field voltage traces. This technique produces results which, though not perfectly accurate, are valid for evaluating the performance of the excitation system. For exciters equipped with transient gain reduction, (Thunder Bay GS) the gain cannot be measured directly, but results obtained can be compared to previous records and to calculated values.

The technique to measure the gain from records is illustrated below. Assume the record taken shows  $E_t$  and  $E_f$  to behave as shown in sketch 5.8.4.

The terminal voltage steady-state value is shown on the record as 22 kV and the full scale sensitivity is 1 kV = 50 divisions. When the disturbance is applied,  $E_t$  changes by 12 divisions (measurement is taken after  $E_t$  has stabilized at its new value) or  $12/50 \times 1 \text{ kV} = 0.24 \text{ kV}$ . In per unit (pu) of rated  $E_t$ , and assuming a rating of 22 kV,

$$\Delta E_t \text{ (pu)} \frac{0.24}{22} = 0.0109 \text{ pu}$$



Sketch 5.8.4  
Measurement of Voltage Regulator Loop Gain

The field voltage trace shows a steady-state value of 250 V, a full scale sensitivity of 1000 V = 50 divisions and a change in  $E_f$  of 17 divisions =  $17/50 \times 1000 = 340$  V. For this particular machine the base field voltage (field voltage required to produce rated terminal voltage on the air gap line with rotor at 75°C) is 131 V. The pu change in  $E_f$  is:

$$\Delta E_f \text{ (pu)} = \frac{340}{131} = 2.60$$

The regulator loop gain is defined as:

$$\text{Gain} = \frac{\Delta E_f \text{ in pu}}{\Delta E_t \text{ in pu}}$$

For the example,

$$G = \frac{2.60}{0.0109} = 238$$

The rated terminal voltage of each generator is available at the station and the base field voltage is available from the unit open circuit saturation curves supplied by the manufacturers.

The gain measurement must be done with a disturbance of 1% or less so as not to force the field voltage to ceiling. Otherwise, if  $E_f$  goes to ceiling the gain measurement will be in error, with the measured gain appearing smaller than it actually is.

## 5.9 Specifications

### Electrical

#### Power Supply

Model: R.O. Associates Model 514 (modified)

Input: 105 to 125 V ac, 47 to 63 Hz

0.25 A at 115 V ac, 60 Hz

Output: +15 V dc, 500 mA

Capable of supplying the power requirements of the stabilizer through a 300 ms ac input interruption.

#### Speed Signal

Frequency: 900 Hz

Amplitude: 5 V to 50 V peak

Input Impedance: 2 k $\Omega$

#### Voltage Limiter

Maximum Input Voltage: 180 V rms at 60 Hz

Range of Limit Starting Setting: 60 V to 180 V

Input Impedance: 15 k $\Omega$ /ø

#### TSEC-1 Card

Maximum regulator  $V_{IN}$  depends on value of  $R_l$

For  $R_l = 2 \text{ k}\Omega$

$V_{IN} \text{ max} = 16 \text{ V peak}$

$R_l = 7.87 \text{ k}\Omega$

$V_{IN} \text{ max} = 25 \text{ V peak}$

Input Impedance: 10 k $\Omega$  minimum



### Stabilizer Output Signal

Maximum voltage swing is either  $\pm 10$  V, -3 V or +3 V, -10 V into a minimum load impedance of 2 k $\Omega$ . Output limits are chosen to match the polarity of the voltage regulator. The output can withstand a continuous short circuit and recover once the short circuit is removed.

### Output Contacts (Stabilizer Malfunction and TSEC Operation)

VA: 10 at 48 V dc  
25 at 125 V dc  
50 at 250 V dc

### Temperature Range

Operating: 0°C to 55°C  
Storage : -10°C to 75°C

### Insulation Level

1500 V ac or 2000 V dc

### Mechanical

Dimensions: Refer to Figure 5-1 for more details. 43.18 cm x 29.53 cm x 27 cm (17" W x 11-5/8" H x 10-5/8" D)

Weight : 18.5 kg (40 lbs)

Paint : Gray ASA61

### 5.10 Additional System Drawings

#### a) Prints Available from Research Division

Delta-Omega Speed Pickup Arrangement      4942 RD  
for Bruce GS

b) Reference Station Drawings

Generator Excitation System  $\Delta\omega$  &  $\Delta P\omega$   
Stabilizer 64122PL79  
Connection Wiring Diagram

NK21-DE-64122-86

Turbine Generator Gen. Excitation  
 $\Delta\omega$  and  $\Delta P\omega$  Stabilizer Conduct and  
Cable Arrangement

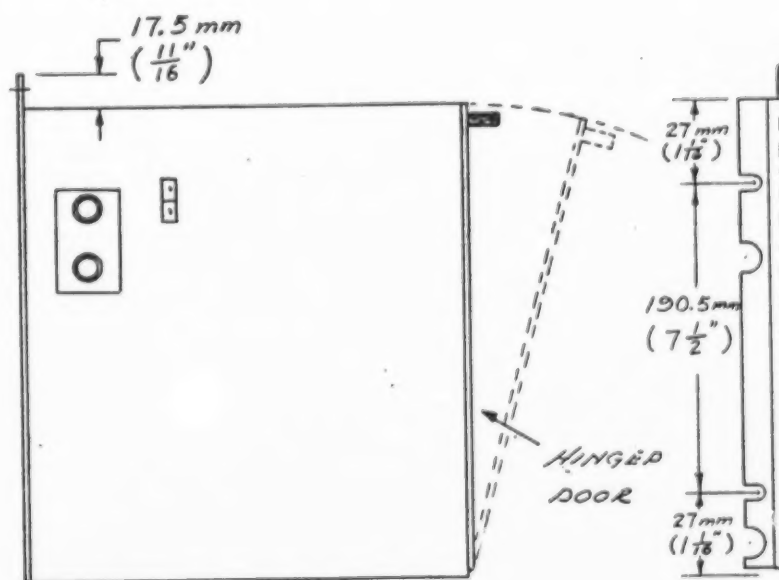
NK21-DE-64122-102

Turbine Generator Gen. Excitation  
 $\Delta\omega$  and  $\Delta P\omega$  Stabilizer Conduct Cable  
Block Diagram

NK21-DE-64122-103

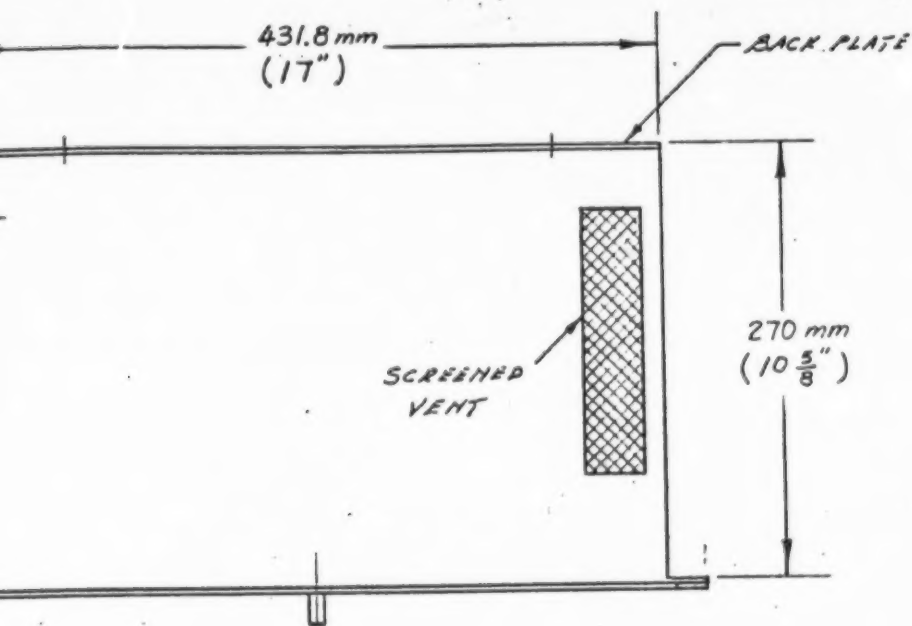
Generator and Ancillary Equipment  
Excitation (Voltage Regulator)  
Elementary Wiring Diagram

NK21-EME-64122-11  
sht 1

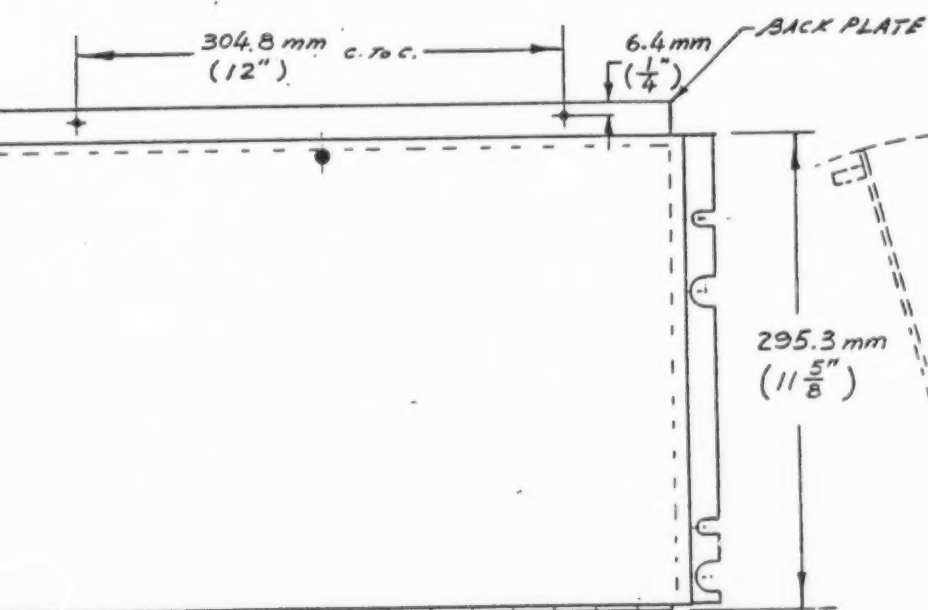


LEFT END VIEW

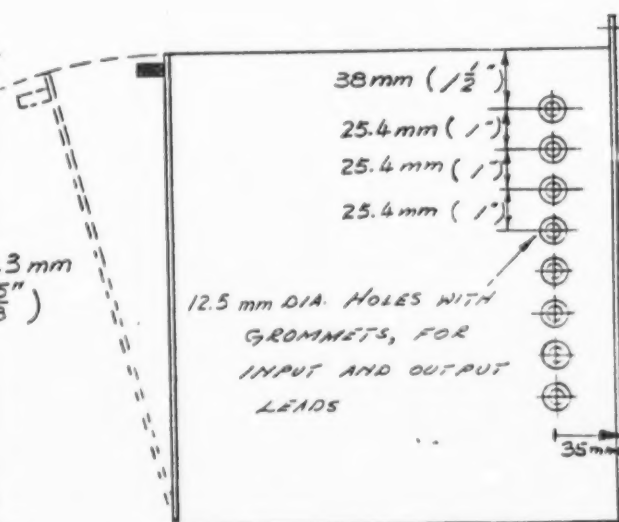
NOTE: BRUCE 'A' Δw STABILIZERS  
HAVE THE SAME CABINET



TOP VIEW



FRONT VIEW



RIGHT END VIEW

FIG. 5-1  
OUTER CABINET FOR  
APW STABILIZER MARK II & IIA

DWG. NO. 29470-RD

REMOVE THE TWO FRONT  
SCREWS FROM UNDERNEATH  
THE STABILIZER AND PUT THEM  
THROUGH THE HOLES IN THE LONG  
BRACKET AND BACK INTO THE  
STABILIZER.

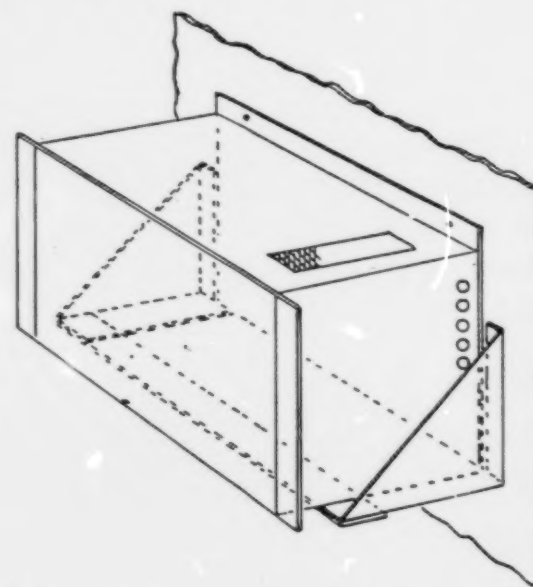
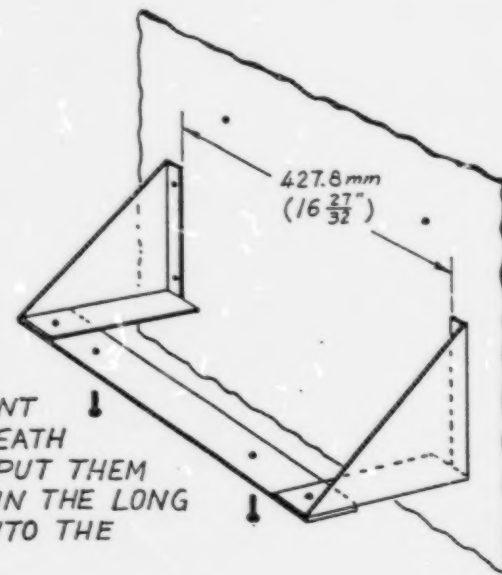
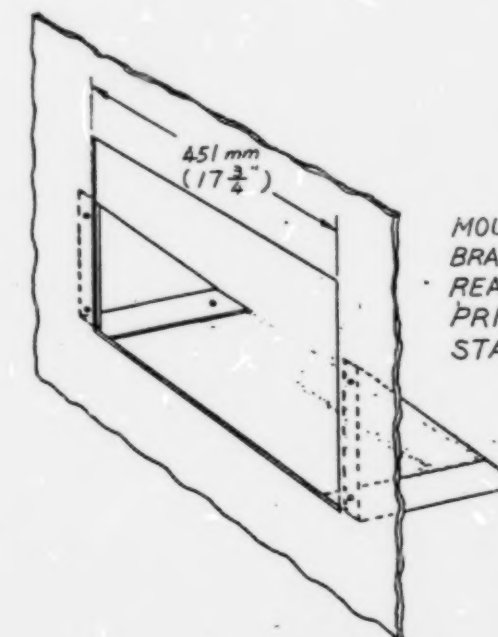


FIG. 5-2(A)  
WALL MOUNTING



MOUNT THE TWO  
BRACKETS FROM THE  
REAR OF RACK OR WALL  
PRIOR TO INSERTING  
STABILIZER CABINET.

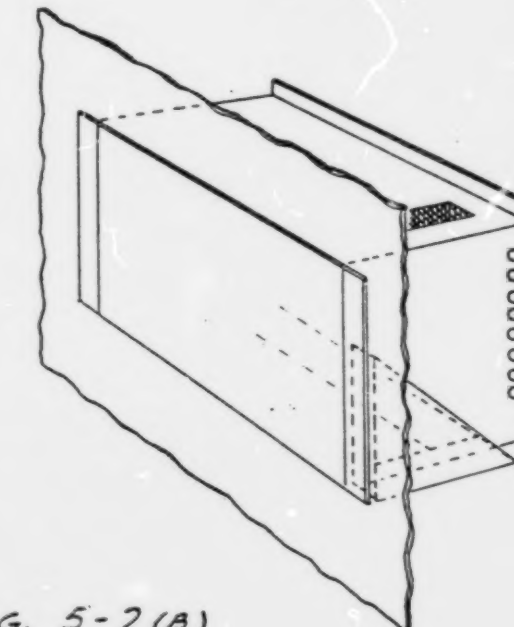
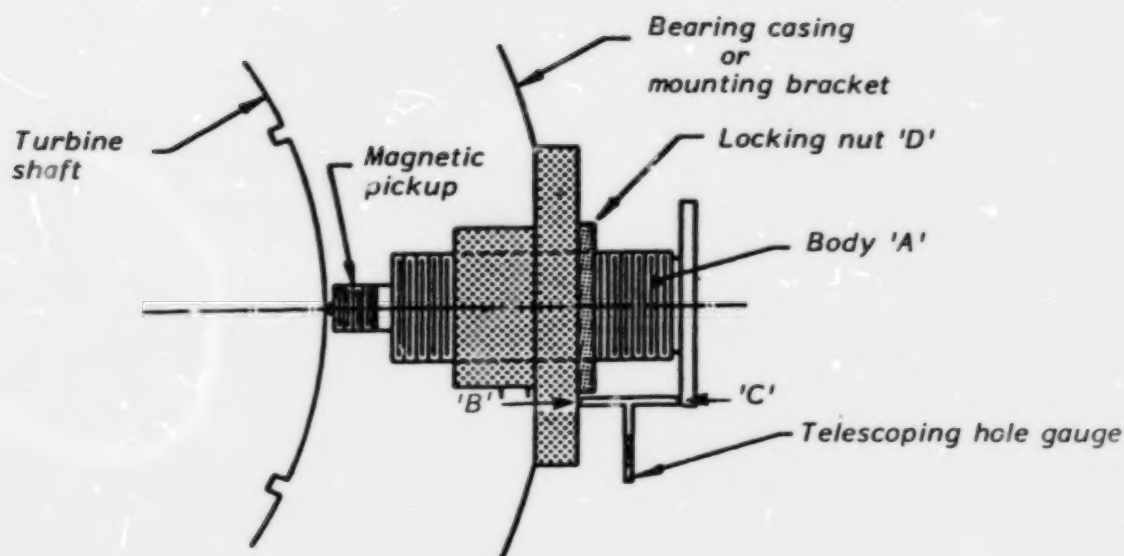


FIG. 5-2(B)  
FLUSH OR RACK MOUNTING

FIG. 5-2  
APW STABILIZER  
MOUNTING ARRANGEMENT

NOTE: BRUCE 'A' Δw STABILIZERS  
HAVE THE SAME CABINET

DWG. 29469-RD



***Suggested method of setting gap spacing***

1. Mount the pickup body on a retaining bracket or casing
2. Ensure that the pickup face is not centred on a slot in turbine shaft
3. Screw body 'A' toward shaft until magnetic pickup just touches turbine shaft
4. Measure distance between points 'B' and 'C' using a telescopic hole gauge. Lock gauge and measure distance with a micrometer
5. Increase above measurement by 0.050 inch and set hole gauge to this value and lock gauge
6. Back-off body 'A' until hole gauge just fits between points 'B' and 'C'
7. Tighten locking nut 'D'

**FIGURE 5-3  
PICKUP ADJUSTMENT - TYPICAL**



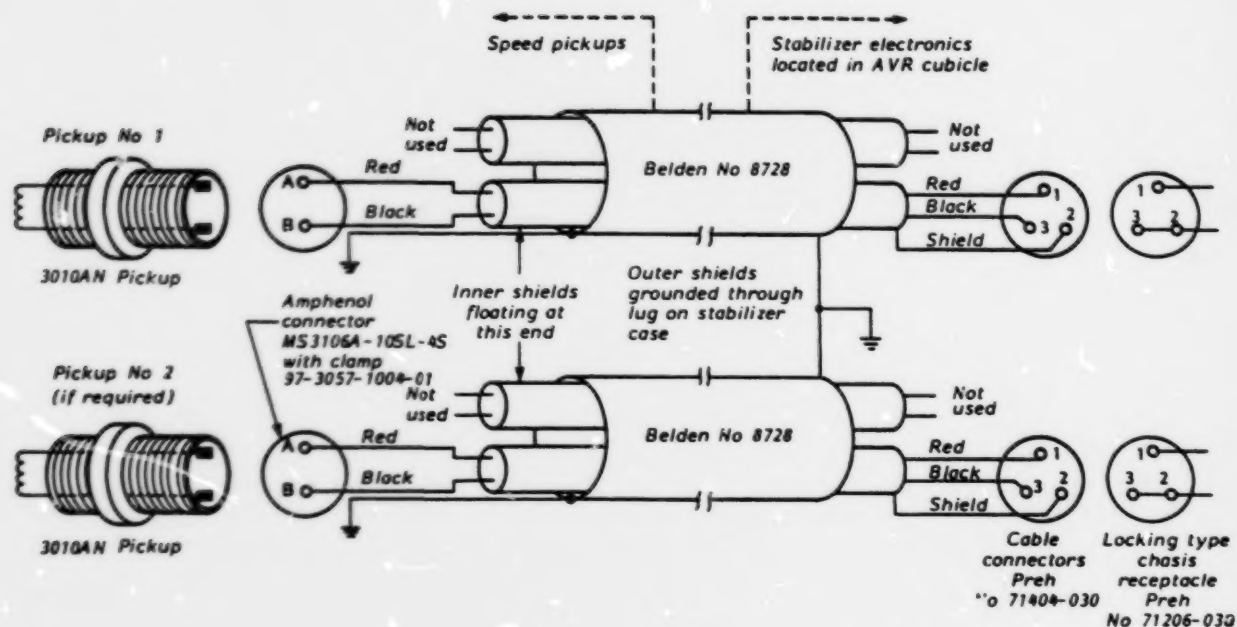


FIGURE 5-4  
SPEED PICKUP WIRING DETAIL FOR THE  $\Delta\omega$  STABILIZER

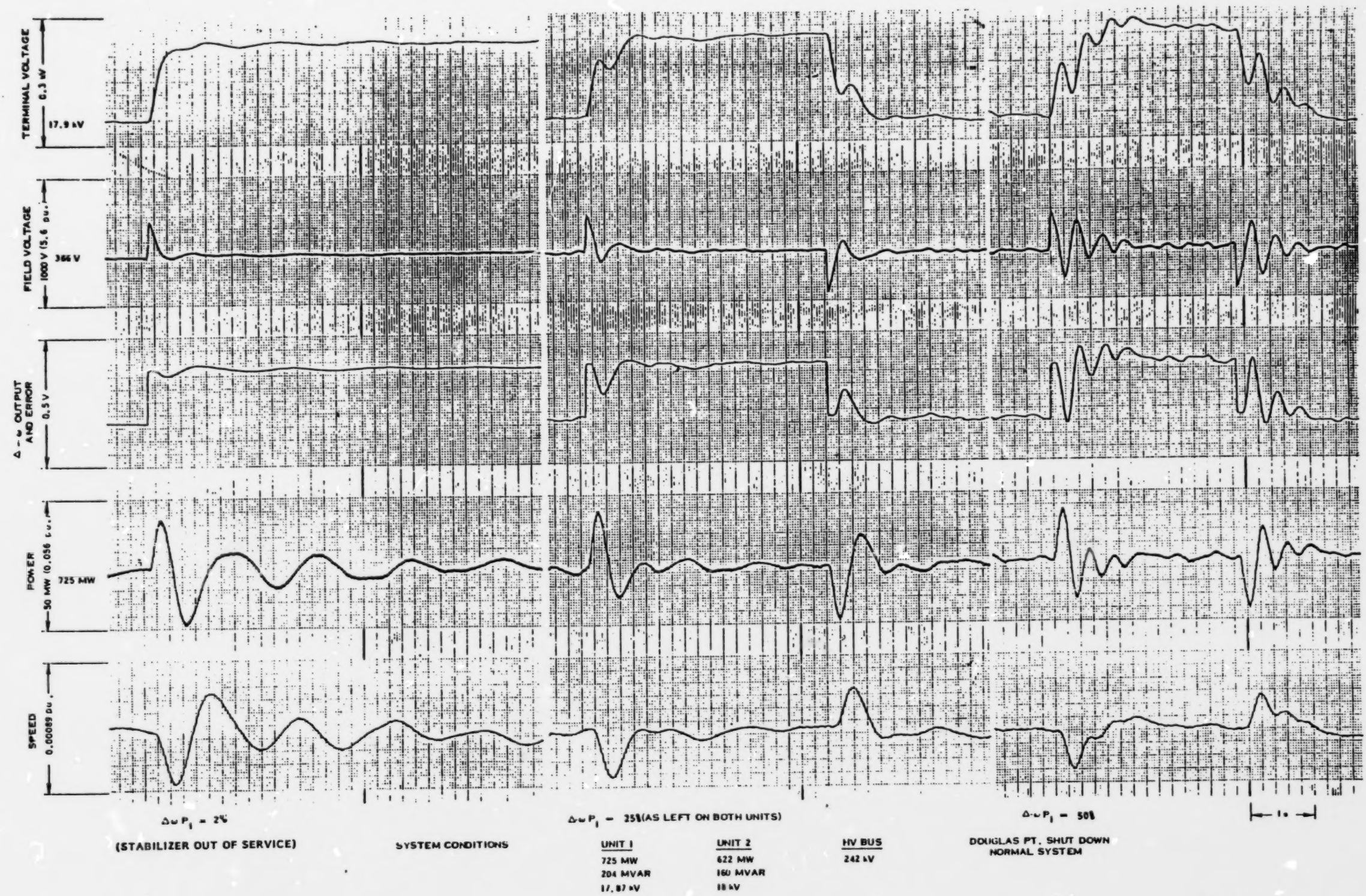
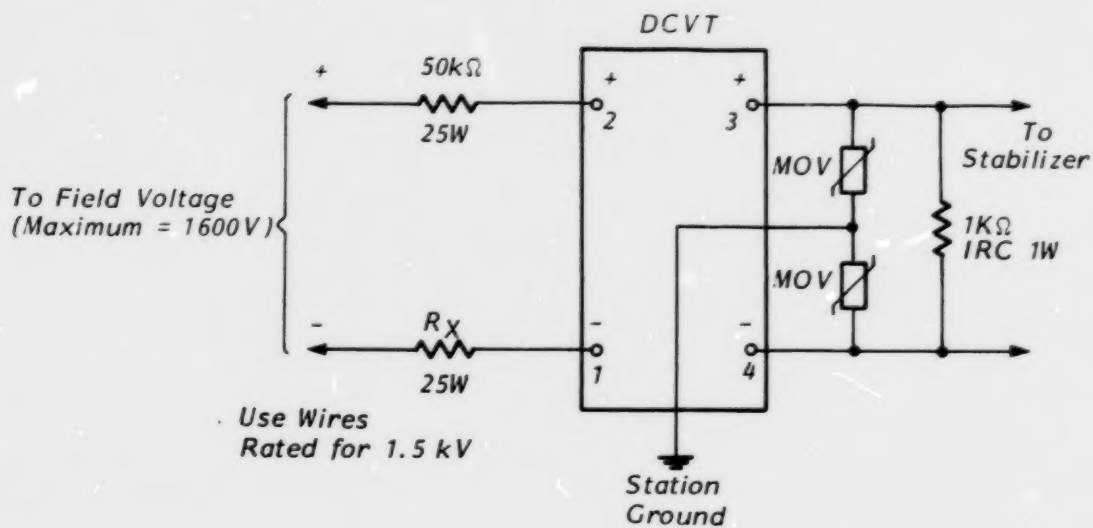


FIGURE 5-5  
EXCITATION SYSTEM RESPONSE TEST  
BRUCE "A" GS, UNIT 1, MARCH 2 1977



- Notes:
1. Mount 50k $\Omega$  Resistors Using Porcelain Mounting Type 768 (Ward Leonard)
  2. 50 k $\Omega$  Resistors are Ward Leonard Type 25/20F 50 k Ohms
  3. MOV's are General Electric V130LA 20B
  4. DCVT is Control Tech Model 4B
  5.  $R_X$  is 50 $\Omega$ k at all stations except Atikokan where  $R_X = 25$ k $\Omega$

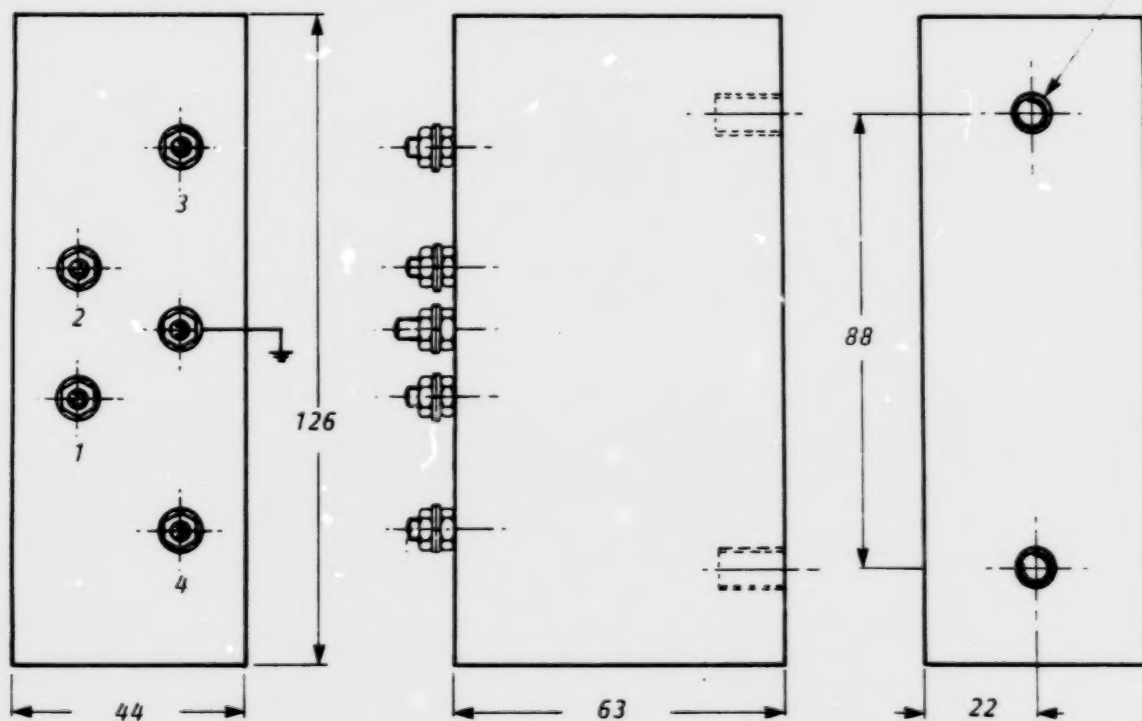


FIGURE 5-6  
WIRING & MOUNTING DIAGRAM FOR THE  
FIELD VOLTAGE TRANSDUCER

## SECTION 6

### PARTS LISTS AND DATA SHEETS

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PARTS LISTS AND DATA SHEETS

6.1 MISCELLANEOUS HARDWARE

Quantity

Edge Connectors

EDAC Canada 307-022-501-102

20

Capacitor

Phillips C2800Cq-A470K 0.47  $\mu$ F, 600 V

1

Filter

RFI Components Corp #7106  
3 Amps 115/280 V AC

1

Cable

Pickup Leads Belden #8728

## 6.2 BOARD CBB-1 - SPEED SIGNAL INPUT

### Resistors

|           |                         |                |
|-----------|-------------------------|----------------|
| R1 to R4  | 1 RC RG 1/4 5% 1/4 Watt | 1.0 k $\Omega$ |
| R5, R7    | 1 RC RG 1/4 5% 1/4 Watt | 10 k $\Omega$  |
| R6, R8    | 1 RC RG 1/4 5% 1/4 Watt | 3.9 k $\Omega$ |
| R9 to R11 | 1 RC RG 1/4 5% 1/4 Watt | 1 k $\Omega$   |
| R12, R13  | 1 RC RG 1/4 5% 1/4 Watt | 3.3 k $\Omega$ |
| R14       | 1 RC RG 1/4 5% 1/4 Watt | 22 k $\Omega$  |

### Trimpots

P10K Beckman Cermet 77PR10K

### Capacitors

|          |                          |                       |
|----------|--------------------------|-----------------------|
| C1 to C2 | Cornell Dubilier WNF1D22 | 0.0022 $\mu$ F 100 V  |
| C3       | Cornell Dubilier WMF1D47 | 0.0047 $\mu$ F 100 V  |
| C4 to C6 | Erie 5855-000 YSU503Z    | 0.05 $\mu$ F 25 V     |
| C7       | Phillips C280CF/P33K     | 0.03 $\mu$ F 400 V dc |

### Diodes

|          |                         |
|----------|-------------------------|
| D1 to D6 | Fairchild IN4148        |
| D7 to D8 | Phillips IN698 or IN478 |

### Integrated Circuits

|          |                               |
|----------|-------------------------------|
| Q1 to Q2 | National semiconductor LM311D |
| Q3       | National semiconductor LM309H |
| Q4       | Texas 7202 SN74121N           |

### Miscellaneous

Printed Circuit Board CBB-1  
Front Panel (marked input)  
#016-8010 (Carsten Electronics)  
Test point jacks - "Sealelectro"  
Handle  
IC sockets 14 pin #12940



### 6.3 BOARD CBB-2 - TACH

#### Resistors

|            |                    |                |
|------------|--------------------|----------------|
| R1 to R4   | RG 1/4 5% 1/4 Watt | 470 $\Omega$   |
| R5         | RG 1/4 5% 3 Watt   | 220 $\Omega$   |
| R6         | RG 1/4 5% 1/4 Watt | 10 k $\Omega$  |
| R7         | RG 1/4 5% 1/4 Watt | 6.8 k $\Omega$ |
| R8         | RG 1/4 5% 1/4 Watt | 4.7 k $\Omega$ |
| R9         | RG 1/4 5% 1/4 Watt | 910 $\Omega$   |
| R10 to R28 | RG 1/4 5% 1/4 Watt | 1.8 k $\Omega$ |

#### Capacitors

|          |          |                  |              |          |
|----------|----------|------------------|--------------|----------|
| C3 to C8 | Phillips | C344CH/A220K     | 0.22 $\mu$ F | 100 V dc |
| C1 to C2 | Erie     | 5855-000 YSU503Z | 0.05 $\mu$ F | 25 V dc  |
| C9       | Elmenco  | DM15-101K        | 100 pF       |          |

#### Diodes

|          |                |          |                 |
|----------|----------------|----------|-----------------|
| D1       | Motorola Zener | (11.7 V) | IN941A          |
| D2 to D3 | Motorola       |          | IN0A47 or IN698 |
| D4 to D5 | Fairchild      |          | IN4148          |

#### Transistors

|          |          |        |
|----------|----------|--------|
| Q1 to Q2 | Motorola | 2N4924 |
|----------|----------|--------|

#### Integrated Circuits

|    |          |             |
|----|----------|-------------|
| Q7 | Motorola | MC1741S CP1 |
|----|----------|-------------|

#### Transformers

|    |                                  |
|----|----------------------------------|
| T1 | Leonard Electric Airpax Magmeter |
|    | 175-991-007 (1000 Hz)            |

#### Miscellaneous

Printed Circuit Board CBB-2  
IC socket Vero 14 pin #12490  
Bakelite - 5/8" x 5/8" x 1/8"  
1 nylon screw & nut 8/32" x 3/4"} mounting for T1  
Front Panel Marked "TACH"  
Test Point Jacks "Sealectro" #016-8010  
Handle

#### 6.4 BOARD CBB-3 - DELTA OMEGA AMP

|            |                        |                |
|------------|------------------------|----------------|
| R1, R8     | IRC RG 1/4 5% 1/4 Watt | 10 k $\Omega$  |
| R2         | IRC RG 1/4 5% 1/4 Watt | 100 k $\Omega$ |
| R3         | IRC RG 1/4 5% 1/4 Watt | 270 $\Omega$   |
| R4 to R5   | IRC RG 1/4 5% 1/4 Watt | 15 k $\Omega$  |
| R6, R7, R9 | IRC RG 1/4 5% 1/4 Watt | 47 k $\Omega$  |
| R10        | IRC RG 1/4 5% 1/4 Watt | 6.8 k $\Omega$ |

#### Potentiometers

|    |                          |                |
|----|--------------------------|----------------|
| P2 | Trimpot - Beckman Cermet | 77PR10K        |
| P1 | Bourns 3501S-1-504       | 500 k $\Omega$ |

#### Capacitors

|        |                                              |                       |
|--------|----------------------------------------------|-----------------------|
| C3     | Kemet Tantalum K470A10K<br>(T111D117K-010AF) | 470 $\mu$ F, 10 V     |
| C5     | Kemet Tantalum K110N10KN                     | 110 $\mu$ F, 100 V    |
| C4     | Cornell Dubilier WMF ID22                    | 0.0022 $\mu$ F, 100 V |
| C6, C7 | Cornell Dubilier WMF ID47                    | 0.0047 $\mu$ F, 100 V |
| C1, C2 | Erie 5855-000 Y5V5032                        | 0.05 $\mu$ F, 25 V    |

#### Diodes

|          |                       |        |
|----------|-----------------------|--------|
| D1, D2   | Fairchild IN4148      |        |
| D5, D6   | Fairchild IN4148      |        |
| D9, D10  | Fairchild IN4148      |        |
| D3, D4   | Motorola Zener IN756A | 8.2 V  |
| D7, D8   | Motorola Zener IN758A | 10.0 V |
| D11, D12 | Motorola Zener IN758A | 10.0 V |

#### Integrated Circuits

|          |                                        |
|----------|----------------------------------------|
| Q1 to Q3 | Fairchild 741 dc operational amplifier |
|----------|----------------------------------------|

#### Miscellaneous

Printed Circuit Board CBB-3  
Integrated Circuit Socket Vero  
pin #12490  
Front Panel Marked " $\Delta$ W AMP"  
Test point jacks "Sealectro" #016-8010 grey  
Knob-Beckman duodial 2607  
Handle

## 6.5 BOARD CBB-4 - FILTER

### Resistors

|                                    |                        |                |
|------------------------------------|------------------------|----------------|
| R1, R2,<br>R7, R8, R15<br>R18, R20 | IRC RG 1/4 5% 1/4 Watt | 10 k $\Omega$  |
| R3, R11                            | IRC RG 1/4 5% 1/4 Watt | 5.6 k $\Omega$ |
| R4                                 | IRC RG 1/4 5% 1/4 Watt | 68 k $\Omega$  |
| R14, R16                           | IRC RG 1/4 5% 1/4 Watt | 100 k $\Omega$ |

- the following resistors supplied and installed by Ontario  
Hydro Research to tune notch frequency

|                                      |                                    |
|--------------------------------------|------------------------------------|
| R5, R6,<br>R9, R10,<br>R12, R13, R19 | Phillips metal film MR25F 1/4 Watt |
|--------------------------------------|------------------------------------|

### Trimpots

|        |                        |
|--------|------------------------|
| P2, P3 | Beckman Cermet 77PR10K |
| P1     | Beckman Cermet 77PR50K |

### Capacitors

|        |                       |                    |
|--------|-----------------------|--------------------|
| C1, C2 | Erie 5855-000 Y5V5032 | 0.05 $\mu$ F, 25 V |
|--------|-----------------------|--------------------|

- the following capacitors supplied and installed by Ontario  
Hydro

|        |                       |                     |
|--------|-----------------------|---------------------|
| C3, C4 | Phillips C344CH/A470K | 0.47 $\mu$ F, 100 V |
| C5     | Phillips C344CH/A3M3  | 3.3 $\mu$ F, 100 V  |
| C6     | Phillips              | 0.1 $\mu$ F, 100 V  |

### Diodes

|           |                       |      |
|-----------|-----------------------|------|
| D1 to D6  | Fairchild IN4148      |      |
| D9 to D14 | Fairchild IN4148      |      |
| D7, D8    | Motorola Zener IN758A | 10 V |
| D15, D16  | Motorola Zener IN758A | 10 V |

### Integrated Circuits

|          |                                  |
|----------|----------------------------------|
| O1 to O6 | Fairchild Operational AMP 741 TC |
|----------|----------------------------------|

### Miscellaneous

Printed Circuit Board CBB-4  
Integrated Circuit Socket Vero 14 Pin #19147  
Front Panel Marked "FILTER"  
Test point jacks, "Sealelectro" #016-8010 (grey)  
Handle

## 6.6 BOARD CBB-5 - OUTPUT

### Resistors

|          |                        |        |
|----------|------------------------|--------|
| R1, R14  | IRC RG 1/4 5% 1/4 Watt | 10 kΩ  |
| R2 to R5 | IRC RG 1/4 5% 1/4 Watt | 47 kΩ  |
| R6       | IRC RG 1/4 5% 1/4 Watt | 3.3 kΩ |
| R8       | IRC RG 1/4 5% 1/4 Watt | 27 kΩ  |
| R10, R17 | IRC RG 1/4 5% 1/4 Watt | 22 kΩ  |
| R11      | IRC RG 1/4 5% 1/4 Watt | 47 kΩ  |
| R12, R16 | IRC RG 1/4 5% 1/4 Watt | 27 kΩ  |
| R15      | IRC RG 1/4 5% 1/4 Watt | 15 kΩ  |
| R9       | IRC RG 1/4 5% 1/4 Watt | 100 Ω  |
| R13      | IRC RG 1/4 5% 1/4 Watt | 1 MΩ   |

R7 - supplied and installed by Ontario Hydro Research

### Trimpots

P1 Beckman Cermet #77PR10K

### Capacitors

|        |                       |                 |
|--------|-----------------------|-----------------|
| C1, C2 | Erie 5855-000 Y5V5032 | 0.05 μF, 25 V   |
| C4     | Phillips              | 0.068 μF, 100 V |
| C5, C6 | Cornell Dubilier      | 500 μF, 50 V    |
| C3     | Phillips C280CF/P22K  | 0.022 μF, 400 V |

### Diodes

|          |                              |       |
|----------|------------------------------|-------|
| D3, D4,  | Fairchild IN4148             |       |
| D8, D9,  | Fairchild IN4148             |       |
| D11, D12 | Fairchild IN4148             |       |
| D2, D5   | Motorola Zener IN746A        | 3.3 V |
| D1, D10  | Motorola Zener IN758A        | 10 V  |
| D7       | Varo 7128 VS648 diode bridge |       |
| D5       | Motorola Zener IN746A        |       |
| D6       | Fairchild IN4148             |       |

### Transistors

Q2, Q3, Texas 2N3704  
Q5

### Integrated Circuits

O1 Fairchild Operational AMP 741 TC  
O4 Motorola MC668P

### Relays

RE1, RE3 CP Clare HGSR 11111 Q00  
RE2 CP Clare HGJ2MT 54211L00

### Transformer

Hammond 227-H

### Miscellaneous

Printed Circuit Board CBB-5  
Integrated Circuit Socket 14 pin Vero #12490  
Integrated Circuit Socket 8 pin Vero #19147  
Front Panel Marked "OUTPUT AMP"  
Test Panel Jacks, "Sealector" #016-8010 (grey)  
Switch J-B-T sub-miniature #JMT-323  
Handle

## 6.7 BOARD CBB-6 - PHASE LEAD

### Resistors

|          |                        |                |
|----------|------------------------|----------------|
| R1, R2   | IRC RG 1/4 5% 1/4 Watt | 2.7 k $\Omega$ |
| R3 to R5 | IRC RG 1/4 5% 1/4 Watt | 15 k $\Omega$  |

### Potentiometer

|    |                                |
|----|--------------------------------|
| P1 | Ohmite 100K dual pot, #CCV1041 |
| P2 | Ohmite 50K, 1/2 Watt, #ASM6669 |

### Capacitors

|        |                            |                    |
|--------|----------------------------|--------------------|
| C1, C2 | Erie 5855-000-Y5V5032      | 0.05 $\mu$ F, 25 V |
| C5     | Phillips C344CH/A100K      | 0.1 $\mu$ F, 100 V |
| C4     | Phillips C344CH/A1M        | 1 $\mu$ F, 100 V   |
| C3     | Phillips C344CH/A4M7       | 4.7 $\mu$ F, 100 V |
| C6     | Kemet Tantilem K110N 10 KN | 110 $\mu$ F, 10 V  |

### Diodes

|        |                       |      |
|--------|-----------------------|------|
| D1, D2 | Fairchild IN4148      |      |
| D5, D6 | Fairchild IN4148      |      |
| D3, D4 | Motorola Zener IN758A | 10 V |
| D7, D8 | Motorola Zener IN758A | 10 V |

### Integrated Circuits

|        |                         |
|--------|-------------------------|
| Q1, Q2 | Fairchild OP AMP 741 TC |
|--------|-------------------------|

### Miscellaneous

Printed Circuit Board CBB-6  
Integrated Circuit Socket 8 pin Vero #19147  
Front Panel Marked "PHASE LEAD"  
Test points "Sealectro" #016-8010 (grey)  
Knobs - Kurz - Kasch S-1645-5L (for P2)  
          - Kurz - Kasch S-1645-3L (for P1)  
Handle

## 6.8 BOARD AP<sub>0</sub> 7C - VOLTAGE LIMITER

### Resistors (1/4W, 1%)

|      |                |               |
|------|----------------|---------------|
| R-1  | Phillips MR25F | 1 kΩ          |
| R-2  | Phillips MR25F | 10 kΩ         |
| R-3  | Phillips MR25F | 475 kΩ        |
| R-4  | Phillips MR25F | 422 kΩ        |
| R-5  | Phillips MR25F | Selected kΩ   |
| R-6  | Phillips MR25F | 47.5 kΩ       |
| R-7  | Phillips MR25F | 10 kΩ         |
| R-8  | Phillips MR25F | Selected kΩ   |
| R-9  | Phillips MR25F | 100 kΩ        |
| R-10 | Phillips MR25F | 10 kΩ         |
| R-11 | Phillips MR25F | 10 kΩ         |
| R-12 | Phillips MR25F | 10 kΩ         |
| R-13 | Phillips MR25F | 10 kΩ         |
| R-14 | Phillips MR25F | Not Installed |
| R-15 | Phillips MR25F | Selected kΩ   |
| R-16 | Phillips MR25F | 10 kΩ         |
| R-17 | Phillips MR25F | Selected kΩ   |
| R-18 | Phillips MR25F | 475 kΩ        |
| R-19 | Phillips MR25F | 10 kΩ         |
| R-20 | Phillips MR25F | 1 kΩ          |
| R-21 | Phillips MR25F | Not Installed |
| R-22 | Phillips MR25F | 10 kΩ         |

### Potentiometers

|      |                       |      |
|------|-----------------------|------|
| Pl-7 | Beckman Helipot S8136 | 1 kΩ |
|------|-----------------------|------|

### Capacitors

|     |                    |                 |
|-----|--------------------|-----------------|
| C-1 | Centralab UK25-503 | 0.05/25V/20%    |
| C-2 | Centralab UK25-503 | 0.05/25V/20%    |
| C-3 | Phillips 03158229  | 22/63V/+50,-10% |
| C-4 | Phillips 34421225  | Not Installed   |
| C-5 | Phillips 34421225  | 2.2/100V/10%    |
| C-6 |                    | Not Installed   |
| C-7 |                    | Not Installed   |

### Diodes

|      |                         |               |
|------|-------------------------|---------------|
| D-1  | International Rectifier | IN4005        |
| D-2  | International Rectifier | IN4005        |
| D-3  | International Rectifier | IN4005        |
| D-4  | International Rectifier | IN4005        |
| D-5  | International Rectifier | IN4005        |
| D-6  | International Rectifier | IN4005        |
| D-7  | Motorola Zener (13V)    | IN5243B       |
| D-8  | International Rectifier | IN4005        |
| D-9  | Motorola Zener (13V)    | IN5243B       |
| D-10 | Motorola Zener (5.1V)   | IN5231        |
| D-11 |                         | Not Installed |
| D-12 |                         | Not Installed |
| D-13 | International Rectifier | IN4005        |
| D-14 | Motorola Zener (13V)    | IN5243B       |
| D-15 | International Rectifier | IN4005        |

### Integrated Circuits

|     |                                    |             |
|-----|------------------------------------|-------------|
| Q-1 | Precision Monolithic Op Amp        | OP-07CP(EP) |
| Q-2 | Precision Monolithic Op Amp        | OP-07CP(EP) |
| Q-3 | Precision Monolithic Op Amp        | OP-07CP(EP) |
| Q-4 | Not Used at Bruce 'B' and Atikokan |             |

### Transformers

|     |                   |      |
|-----|-------------------|------|
| T-1 | Hammond 115/15/15 | 226F |
| T-2 | Hammond 115/15/15 | 226F |
| T-3 | Hammond 115/15/15 | 226F |



## 6.9 BOARD CBB-8 - POWER SUPPLY MOUNTING

### Resistors

|              |                        |               |
|--------------|------------------------|---------------|
| R1 to R6, R9 | IRC RG 1/4 5% 1/4 Watt | 10 k $\Omega$ |
| R7           | IRC RG 1/4 5% 1/4 Watt | 1 M $\Omega$  |
| R8, R10, R11 | IRC RG 1/4 5% 1/4 Watt | 100 $\Omega$  |

### Capacitors

|        |                                  |                      |
|--------|----------------------------------|----------------------|
| C1, C2 | Erie 5855-000-Y5V503Z            | 0.05 $\mu$ F, 25 V   |
|        | Phillips electrolytic capacitors |                      |
| C4     | - C432LF/G10 000                 | 10 000 $\mu$ F, 40 V |
| C5     | - C431CR/G1000                   | 1 000 $\mu$ F, 40 V  |

### Diodes

|          |                             |
|----------|-----------------------------|
| D2 to D4 | Motorola IN4148             |
| D1       | Motorola IN758A 10 V Zener  |
| D6       | Motorola IN5365A 36 V Zener |
| D5, D7   | Motorola IN4005             |

### Integrated Circuits

|    |                               |
|----|-------------------------------|
| O1 | National Semiconductor LM311D |
|----|-------------------------------|

### Transistor

|    |              |
|----|--------------|
| Q2 | Texas 2N3704 |
|----|--------------|

### Relay

|     |                            |
|-----|----------------------------|
| RE1 | C.P. Clare HGJ2MT 54211L00 |
|-----|----------------------------|

### Power Supply

R.O. Associates,  $\pm 15$  V, 500 mA model 514

### Miscellaneous

- Switch - JBT Sub-miniature switch JMT-223 (DPDT)
- Lamps - Dialco lamp holder 508-7538-504
- Dialco lamp 507-4537-1531-640
- Fuse - fuse holder - Bus HTA
- fuse -1/4 x 1-1/4 x 2 amps
- Front Panel Marked "POWER SUPPLY"
- Test Point Jacks, "Sealectro" #016-8010 (grey)
- Printed Circuit Board CBB-8
- Blank Circuit Board
- Integrated Circuit Socket Vero 14 pin #12490
- Cinch-Hanes edge connector 50-15A-20
- Handle
- Spacers - Herman H. Smith - #2102 1/2"
- Spacers - Herman H. Smith - #2101 3/8"
- Spacers - Herman H. Smith - #2104 1"

#### 6.10 BOARD CBB-9 - MISSING PULSE

|                    |                        |                |
|--------------------|------------------------|----------------|
| R1, R6             | IRC RG 1/4 5% 1/4 Watt | 910 $\Omega$   |
| R3, R8             | IRC RG 1/4 5% 1/4 Watt | 820 $\Omega$   |
| R15, R17           | IRC RG 1/4 5% 1/4 Watt | 1 k $\Omega$   |
| R4, R5,<br>R9, R10 | IRC RG 1/4 5% 1/4 Watt | 2.2 k $\Omega$ |
| R19                | IRC RG 1/4 5% 1/4 Watt | 3.3 k $\Omega$ |
| R16, R18           | IRC RG 1/4 5% 1/4 Watt | 3.9 k $\Omega$ |
| R14, R32           | IRC RG 1/4 5% 1/4 Watt | 22 k $\Omega$  |
| R20                | IRC RG 1/4 5% 1/4 Watt | 6.8 k $\Omega$ |
| R21, R33           | IRC RG 1/4 5% 1/4 Watt | 10 k $\Omega$  |
| R2, R7             | IRC RG 1/4 5% 1/4 Watt | 27 k $\Omega$  |
| R11, R12           | IRC RG 1/4 5% 1/4 Watt | 50 k $\Omega$  |
| R13                |                        |                |
| R22 to R24,        | IRC RG 1/4 5% 1/4 Watt | 100 k $\Omega$ |
| R27, R28,          | IRC RG 1/4 5% 1/4 Watt | 100 k $\Omega$ |
| R31                |                        |                |
| R25, R26,          | IRC RG 1/4 5% 1/4 Watt | 1 M $\Omega$   |
| R29, R30           |                        |                |

- following resistors to be installed by Ontario Hydro Research

R\* IRC RG 1/4 5% 1/4 Watt

- to be used in place of P1 if desired.

#### Capacitors

|         |                       |                     |
|---------|-----------------------|---------------------|
| C1, C2  | Erie 5855-000 Y5V503Z | 0.05 $\mu$ F, 25 V  |
| C9, C11 | Phillips C344CH/A100K | 0.1 $\mu$ F, 100 V  |
| C10     | Phillips C344CH/A470K | 0.47 $\mu$ F, 100 V |
| C5, C6  | Phillips C344CH/AlM   | 1 $\mu$ F, 100 V    |

- to be supplied and installed by Ontario Hydro Research

|        |                      |                     |
|--------|----------------------|---------------------|
| C3, C4 | Phillips C280CF/A10K | 0.01 $\mu$ F, 400 V |
| C8, C7 |                      |                     |

#### Diodes

D1 to D14 Fairchild IN4148

#### Voltage Regulator

Q4, Q5 National Semiconductors LM320H-5.0

#### Potentiometer

P1 Bourns 10 turn, dual 5 k $\Omega$  pot or equivalent

#### Integrated Circuits

O1, O2, O3 Fairchild OP AMP 741 TC  
O6, Q7 National Semiconductor LM 319D

#### Miscellaneous

Printed Circuit Board CBB-9  
Integrated Circuit Socket Vero 14 pin #12490  
Integrated Circuit Socket Vero 8 pin #19147  
Test point jacks, "Sealelectro" #016-8010 (grey)  
NF-205 Delta-T series snap on cooler (for Q4 & Q5)  
Handle

## 6.11 BOARD APw 13-1 - TSEC 1-1

Resistors (1/4W, 1%)

|      |                |          |
|------|----------------|----------|
| R-1  | Phillips MR25F | 10 kΩ    |
| R-2  | Phillips MR25F | 10 kΩ    |
| R-3  | Phillips MR25F | 909 ohms |
| R-4  | Phillips MR25F | 1.82 kΩ  |
| R-5  | Phillips MR25F | 1.82 kΩ  |
| R-6  | Phillips MR25F | 1.82 kΩ  |
| R-7  | Phillips MR25F | 1.82 kΩ  |
| R-8  | Phillips MR25F | 1.82 kΩ  |
| R-9  | Phillips MR25F | 909 ohms |
| R-10 | Phillips MR25F | 6.81 kΩ  |
| R-11 | Phillips MR25F | 124 kΩ   |
| R-12 | Phillips MR25F | 22 kΩ    |
| R-13 | Phillips MR25F | 4.99 kΩ  |
| R-14 | Phillips MR25F | 4.99 kΩ  |
| R-15 | Phillips MR25F | 169 kΩ   |
| R-16 | Phillips MR25F | 10 kΩ    |
| R-17 | Phillips MR25F | 30.1 kΩ  |
| R-18 | Phillips MR25F | 10 kΩ    |
| R-19 | Phillips MR25F | 22.1 kΩ  |
| R-20 | Phillips MR25F | 12.1 kΩ  |
| R-21 | Phillips MR25F | 100 kΩ   |
| R-22 | Phillips MR25F | 47.5 kΩ  |
| R-23 | Phillips MR25F | 33.2 kΩ  |
| R-24 | Phillips MR25F | 100 kΩ   |
| R-25 | Phillips MR25F | 10 kΩ    |
| R-26 | Phillips MR25F | 10 kΩ    |
| R-27 | Phillips MR25F | 10 kΩ    |
| R-28 | Phillips MR25F | 4.75 kΩ  |
| R-29 | Phillips MR25F | 49.5 kΩ  |
| R-30 | Phillips MR25F | 33.2 kΩ  |
| R-31 | Phillips MR25F | 10.7 kΩ  |
| R-32 | Phillips MR25F | 10 kΩ    |
| R-33 | Phillips MR25F | 10 kΩ    |
| R-34 | Phillips MR25F | 10 kΩ    |
| R-35 | Phillips MR25F | 10 kΩ    |

Capacitors

|      |                               |           |       |     |
|------|-------------------------------|-----------|-------|-----|
| C-1  | Centralab UF25-503            | 0.05 μF   | 25 V  | 20% |
| C-2  | Centralab UF25-503            | 0.05 μF   | 25 V  | 20% |
| C-3  | Cornell Dubilier WMF1D47      | 0.0047 μF | 100 V | 10% |
| C-4  | Phillips 34421224             | 0.22 μF   | 100 V | 10% |
| C-5  | Phillips 34421224             | 0.22 μF   | 100 V | 10% |
| C-6  | Phillips 34421224             | 0.22 μF   | 100 V | 10% |
| C-7  | Phillips 34421244             | 0.22 μF   | 100 V | 10% |
| C-8  | Phillips 34421244             | 0.22 μF   | 100 V | 10% |
| C-9  | Phillips 34421244             | 0.22 μF   | 100 V | 10% |
| C-10 | Sprague Elec 150 D477 x 9010S | 470 μF    | 10 V  | 20% |
| C-11 | Cornell Dubilier WMF1D47      | 0.0047 μF | 100 V | 10% |
| C-12 | Phillips 34421475             | 4.7 μF    | 100 V | 10% |
| C-13 | Cornell Dubilier WMF1D47      | 0.0047 μF | 100 V | 10% |
| C-14 | Phillips 34421104             | 0.1 μF    | 100 V | 10% |
| C-15 | Sprague Elec 151D117x9010Z0   | 110 μF    | 10 V  | 20% |
| C-16 | Phillips 34421104             | 0.1 μF    | 100 V | 10% |

Diodes

|     |                              |         |
|-----|------------------------------|---------|
| D-1 | Motorola Zener Diode (7.5 V) | IN5236B |
| D-2 | Short                        |         |
| D-3 | Motorola Zener Diode (10 V)  | IN758A  |
| D-4 | Motorola Zener Diode (10 V)  | IN758A  |
| D-5 | Short                        |         |
| D-6 | Motorola Zener Diode (5.1 V) | IN5231B |
| D-7 | Motorola Zener Diode (10 V)  | IN758A  |

Integrated Circuits

|     |                             |         |
|-----|-----------------------------|---------|
| O-1 | Precision Monolithic Op Amp | OP-07CP |
| O-2 | Precision Monolithic Op Amp | OP-07CP |
| O-3 | Precision Monolithic Op Amp | OP-07CP |
| O-4 | Precision Monolithic Op Amp | OP-07CP |
| O-5 | Precision Monolithic Op Amp | OP-07CP |
| O-6 | Precision Monolithic Op Amp | OP-07CP |
| O-7 | Precision Monolithic Op Amp | OP-07CP |
| O-8 | Precision Monolithic Op Amp | OP-07CP |

Relay

|      |            |           |
|------|------------|-----------|
| RE-5 | Magnecraft | W171D1P-7 |
|------|------------|-----------|

Potentiometers

|     |                 |       |
|-----|-----------------|-------|
| P-1 | Spectrol 642103 | 10 kΩ |
| P-2 | Spectrol 642103 | 10 kΩ |
| P-3 | Spectrol 642103 | 10 kΩ |

Switch

|       |                  |         |
|-------|------------------|---------|
| SW-13 | JBT Subminiature | JMT-123 |
|-------|------------------|---------|

## 6.12 BOARD AP-14 A - TSEC 2A

Resistors (1/4W, 1%)

|      |                |                 |
|------|----------------|-----------------|
| R-1  | Phillips MR25F | 6.98 k $\Omega$ |
| R-2  | Phillips MR25F | 10 k $\Omega$   |
| R-3  | Phillips MR25F | 0.0             |
| R-4  | Phillips MR25F | 100 k $\Omega$  |
| R-5  | Phillips MR25F | 4.75 k $\Omega$ |
| R-6  | Phillips MR25F | 100 k $\Omega$  |
| R-7  | Phillips MR25F | 10 k $\Omega$   |
| R-8  | Phillips MR25F | 68.1 k $\Omega$ |
| R-9  | Phillips MR25F | 22.1 k $\Omega$ |
| R-10 | Phillips MR25F | 127 k $\Omega$  |
| R-11 | Phillips MR25F | 2.21 k $\Omega$ |
| R-12 | Phillips MR25F | 10 k $\Omega$   |
| R-13 | Phillips MR25F | 2.4 M $\Omega$  |
| R-14 | Phillips MR25F | 1.5 M $\Omega$  |
| R-15 | Phillips MR25F | 100 k $\Omega$  |
| R-16 | Phillips MR25F | 10 k $\Omega$   |
| R-17 | Phillips MR25F | 1.5 k $\Omega$  |
| R-18 | Phillips MR25F | 27.4 ohms       |
| R-19 | Ohmite 5864    | 100 ohms 5 W    |
| R-20 | Phillips MR25F | 10 k $\Omega$   |
| R-21 | Phillips MR25F | 10 k $\Omega$   |
| R-22 | Phillips MR25F | 499 k $\Omega$  |
| R-23 | Phillips MR25F | 2.21 k $\Omega$ |
| R-24 | Phillips MR25F | 10 k $\Omega$   |
| R-25 | Phillips MR25F | 162 k $\Omega$  |
| R-26 | Phillips MR25F | 10 k $\Omega$   |
| R-27 | Phillips MR25F | 10 k $\Omega$   |
| R-28 | Phillips MR25F | 332 k $\Omega$  |
| R-29 | Phillips MR25F | 10 k $\Omega$   |
| R-30 | Phillips MR25F | 10 k $\Omega$   |
| R-31 | Phillips MR25F | 21.5 k $\Omega$ |
| R-32 | Phillips MR25F | 22.1 k $\Omega$ |
| R-33 | Phillips MR25F | 2.21 k $\Omega$ |
| R-34 | Phillips MR25F | 10 k $\Omega$   |
| R-35 | Phillips MR25F | 47.5 k $\Omega$ |
| R-36 | Phillips MR25F | 100 ohms        |
| R-37 | Phillips MR25F | 10 k $\Omega$   |
| R-38 | Phillips MR25F | 1 k $\Omega$    |
| R-39 | Phillips MR25F | 100 k $\Omega$  |
| R-40 | Phillips MR25F | 100 k $\Omega$  |

Capacitors

|      |                           |                           |
|------|---------------------------|---------------------------|
| C-1  | Phillips                  | Not installed             |
| C-2  | Phillips 34421224         | 0.22 $\mu$ F 100 V 10%    |
| C-3  | Cornell Dubilier MMF 1047 | 0.0047 $\mu$ F 100 V 10%  |
| C-4  | Phillips 3442114          | 0.1 $\mu$ F 100 V 10%     |
| C-5  | Phillips                  | 0.1 $\mu$ F 100 V 10%     |
| C-6  | Phillips 3455683          | 0.068 $\mu$ F 400 V 10%   |
| C-7  | Phillips 34255104         | 0.1 $\mu$ F 400 V 10%     |
| C-8  | Phillips 34421225         | 2.2 $\mu$ F 100 V 10%     |
| C-9  | Phillips 34421104         | 0.1 $\mu$ F 100 V 10%     |
| C-10 | Kemet T368C226K035AS      | 22 $\mu$ F 35 V 10%       |
| C-11 | Phillips 34421224         | 0.22 $\mu$ F 100 V 10%    |
| C-12 | Phillips 34421104         | 0.1 $\mu$ F 100 V 10%     |
| C-13 | Cornell Dubilier MMF 1D22 | 0.0022 $\mu$ F 100 V 10%  |
| C-14 | Miconics DM15-501J        | 0.000500 $\mu$ F 500 V 5% |
| C-15 | Centralab UF25-503        | 0.05 $\mu$ F 25 V 20%     |
| C-16 | Centralab UF25-503        | 0.05 $\mu$ F 25 V 20%     |

Diodes

|      |                               |        |
|------|-------------------------------|--------|
| D-1  | Fairchild Diode               | IN4148 |
| D-2  | Fairchild Diode               | IN4148 |
| D-3  | Fairchild Diode               | IN4148 |
| D-4  | Fairchild Diode               | IN4148 |
| D-5  | Fairchild Diode               | IN4148 |
| D-6  | Fairchild Diode               | IN4148 |
| D-7  | Fairchild Diode               | IN4148 |
| D-8  | Fairchild Diode               | IN4148 |
| D-9  | Fairchild Diode               | IN4148 |
| D-10 | Fairchild Diode               | IN4148 |
| D-11 | International Rectifier Diode | IN4005 |
| D-12 | Motorola Zener Diode 10 V     | IN758A |
| D-13 | Motorola Zener Diode 8.2 V    | IN756A |
| D-14 | Monsanto Light Emitting Diode | MV5024 |

Integrated Circuits

|      |                                               |             |
|------|-----------------------------------------------|-------------|
| Q-1  | Precision Monolithic Op Amp                   | OP-07CP     |
| Q-2  | National Semiconductor Volt Comparator        | LM311J-8    |
| Q-3  | National Semiconductor Triple Input Nand Gate | MM74C10N    |
| Q-4  | National Semiconductor Triple Input Nand Gate | MM74C10N    |
| Q-5  | National Semiconductor Volt Comparator        | LM311J-8    |
| Q-6  | Intersil Timer                                | ICM 75551PA |
| Q-7  | Precision Monolithic Op Amp                   | OP-07CP     |
| Q-8  | National Semiconductor Volt Comparator        | LM311J-8    |
| Q-9  | Texas (or equivalent) Transistor              | 2N3704      |
| Q-10 | Texas (or equivalent) Transistor              | 2N3704      |
| Q-11 | Intersil Timer                                | ICM 75551PA |
| Q-12 | Precision Monolithic Op Amp                   | OP-07CP     |

Switch

|       |                  |         |
|-------|------------------|---------|
| SW-14 | JBT Subminiature | JMT-123 |
|-------|------------------|---------|

Relay

|      |               |          |
|------|---------------|----------|
| RE-6 | CP Clare HGJM | 51111P00 |
|------|---------------|----------|

Varistor

|     |                           |         |
|-----|---------------------------|---------|
| MOV | General Electric Varistor | V250LA4 |
|-----|---------------------------|---------|

### 6.13 BOARD 1S01-1 ISOLATOR

#### Resistors (1/4 W, 1%)

|     |                |                |
|-----|----------------|----------------|
| R1  | Phillips MR25F | 221 k $\Omega$ |
| R2  | Phillips MR25F | 221 k $\Omega$ |
| R3  | Phillips MR25F | 221 k $\Omega$ |
| R4  | Phillips MR25F | 100 k $\Omega$ |
| R5  | Phillips MR25F | 100 k $\Omega$ |
| R6  | Phillips MR25F | 100 k $\Omega$ |
| R7  | Phillips MR25F | 5 k $\Omega$   |
| R8  | Phillips MR25F | 10 k $\Omega$  |
| R9  | Phillips MR25F | 10 k $\Omega$  |
| R10 | Phillips MR25F | 221 k $\Omega$ |

#### Capacitors

|    |                    |                    |
|----|--------------------|--------------------|
| C1 | Centralab UK25-503 | 0.05 $\mu$ F, 25 V |
| C2 | Centralab UK25-503 | 0.05 $\mu$ F, 25 V |

#### Integrated Circuits

|    |                               |          |
|----|-------------------------------|----------|
| Q1 | Precision Monolithic OP AMP   | OP07 CP  |
| Q2 | National Semiconductor OP AMP | LM741 CN |

#### Power Supply

|               |                            |               |
|---------------|----------------------------|---------------|
| Datel Systems | DC/DC Converter Power Mite | BPM 15/25-D28 |
|---------------|----------------------------|---------------|

#### Miscellaneous

|                                      |       |   |
|--------------------------------------|-------|---|
| Printed Circuit Board                | ISO-1 | 2 |
| Integrated Circuit Socket Vero 8-Pin |       | 5 |
| Test Point Jacks                     |       | 1 |
| Card Front - Custom                  | ISO-1 | 1 |
| Card Handle - Custom                 |       | 1 |

## DIODES AND MOV

### Zener Diodes

|          |        |        |
|----------|--------|--------|
| IN 5243B | 15.0 V | 400 mW |
| IN 746A  | 3.3 V  | 400 mW |
| IN 756A  | 8.2 V  | 400 mW |
| IN 758A  | 10.0 V | 400 mW |
| IN 5365A | 36 V   | 5 W    |
| IN 5236B | 7.5 V  | 400 mW |
| IN 5231B | 5.1 V  | 400 mW |

### Signal Diodes

|         |          |         |
|---------|----------|---------|
| IN 4148 | 75 V PRV | silicon |
| IN 4451 | 30 V PRV | silicon |

### Rectifier

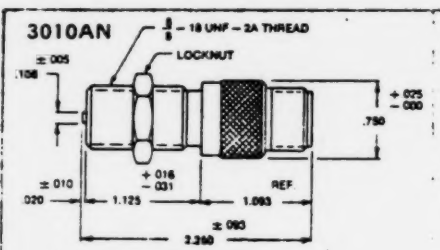
|         |           |    |
|---------|-----------|----|
| IN 4005 | 600 V PRV | 1A |
|---------|-----------|----|

### LED

|          |     |         |
|----------|-----|---------|
| Monsanto | LED | MV 5024 |
|----------|-----|---------|

### MOV

|    |         |       |          |
|----|---------|-------|----------|
| GE | V250LA4 | 250 V | 4 joules |
|----|---------|-------|----------|



#### **SPECIFICATIONS**

##### **Electrical:**

**OUTPUT VOLTAGE:** 40 volts minimum peak-to-peak (Note 1)

**INDUCTANCE:** 25 mH maximum

**DC RESISTANCE:** 85 ohms maximum

**POLARITY:** When ferrous metal is introduced into magnetic field, Pin B will be positive with respect to Pin A.

##### **Mechanical:**

**TEMPERATURE RANGE:** -100°F to +225°F

**MATERIAL:** Stainless Steel for both shell body and pole piece.

**POTTING:** Sensor potted internally with epoxy resin making it oil and moisture resistant.

**MATING CABLE 30N**

**OUTPUT CONNECTION:** Mates with MS3106A-10SL-4S

**NET WEIGHT:** 2.5 ounces (71 grams)

**Model 3010AN.** Standard 1/8" — 18 thread family. Thread length 1.125". General purpose. Output Voltage: 40 volts minimum peak to peak, tested at 1,000 inches per second, with 20 pitch, 30 tooth gear at .005" pole-piece clearance and 100K ohm load. Inductance: 25 mH maximum. DC Resistance: 85 ohms maximum. Polarity: When ferrous metal is introduced into magnetic field, pin B will be positive with respect to pin A. Temperature Range: -100°F to +225°F. Stainless steel for both shell body and pole piece. Sensor potted internally with epoxy resin making it oil and moisture resistant. Mates with MS3106A-10SL-4S connector or Electro 30N cable assembly. Pole piece diameter .106".

**Model 3010AN25.** Same, but with 2.500" thread length.



6-14 Data Sheets



# Operational Amplifiers

## LM741/LM741C operational amplifier

### general description

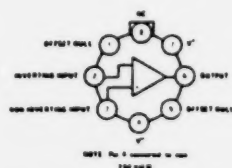
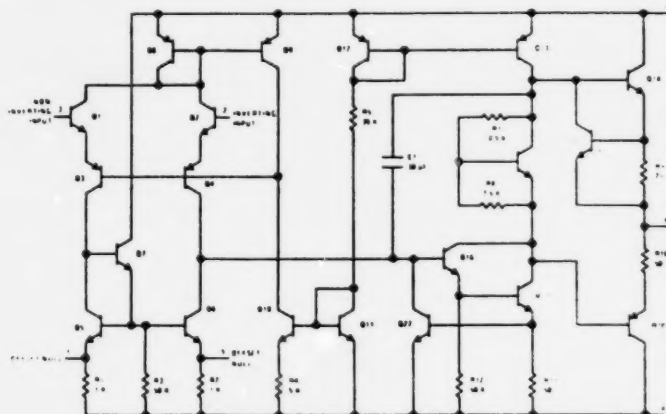
The LM741 and LM741C are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The offset voltage and offset current are guaranteed over the entire common mode range. The amplifiers also offer many features which make

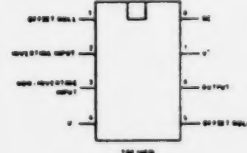
their application nearly foolproof: overload protection on the input and output, no latch up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741 except that the LM741C has its performance guaranteed over a 0°C to 70°C temperature range, instead of -55°C to 125°C.

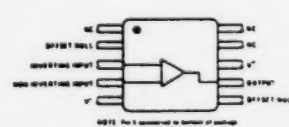
### schematic and connection diagrams



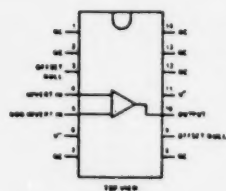
Order Number LM741H or LM741CH  
See Package 11



Order Number LM741CN  
See Package 20



Order Number LM741F  
See Package 3



Order Number  
LM741CD or LM741CN-14  
See Package 1 See Package 22

LM741/LM741C

2

## absolute maximum ratings

|                                      |        |                |
|--------------------------------------|--------|----------------|
| Supply Voltage                       | LM741  | ±22V           |
|                                      | LM741C | ±18V           |
| Power Dissipation (Note 1)           |        | 500 mW         |
| Differential Input Voltage           |        | ±30V           |
| Input Voltage (Note 2)               |        | ±15V           |
| Output Short-Circuit Duration        |        | Indefinite     |
| Operating Temperature Range          | LM741  | -55°C to 125°C |
|                                      | LM741C | 0°C to 70°C    |
| Storage Temperature Range            |        | -66°C to 150°C |
| Lead Temperature (Soldering, 10 sec) |        | 300°C          |

## electrical characteristics (Note 3)

| PARAMETER                      | CONDITIONS                                                                                                 | LM741 |     |     | LM741C |     |     | UNITS         |
|--------------------------------|------------------------------------------------------------------------------------------------------------|-------|-----|-----|--------|-----|-----|---------------|
|                                |                                                                                                            | MIN   | TYP | MAX | MIN    | TYP | MAX |               |
| Input Offset Voltage           | $T_A = 25^\circ\text{C}$ , $R_L \leq 10\text{ k}\Omega$                                                    |       | 1.0 | 5.0 |        | 1.0 | 6.0 | mV            |
| Input Offset Current           | $T_A = 25^\circ\text{C}$                                                                                   |       | 30  | 200 |        | 30  | 200 | nA            |
| Input Bias Current             | $T_A = 25^\circ\text{C}$                                                                                   |       | 200 | 500 |        | 200 | 500 | nA            |
| Input Resistance               | $T_A = 25^\circ\text{C}$                                                                                   | 0.3   | 1.0 |     | 0.3    | 1.0 |     | M $\Omega$    |
| Supply Current                 | $T_A = 25^\circ\text{C}$ , $V_S = \pm 15\text{V}$                                                          |       | 1.7 | 2.8 |        | 1.7 | 2.8 | mA            |
| Large Signal Voltage Gain      | $T_A = 25^\circ\text{C}$ , $V_S = \pm 15\text{V}$<br>$V_{OUT} = \pm 10\text{V}$ , $R_L > 2\text{ k}\Omega$ | 50    | 180 |     | 25     | 180 |     | V/mV          |
| Input Offset Voltage           | $R_L \leq 10\text{ k}\Omega$                                                                               |       |     | 8.0 |        |     | 7.5 | mV            |
| Input Offset Current           |                                                                                                            |       |     | 500 |        |     | 300 | nA            |
| Input Bias Current             |                                                                                                            |       |     | 1.5 |        |     | 0.8 | $\mu\text{A}$ |
| Large Signal Voltage Gain      | $V_S = \pm 15\text{V}$ , $V_{OUT} = \pm 10\text{V}$<br>$R_L > 2\text{ k}\Omega$                            | 25    |     |     | 15     |     |     | V/mV          |
| Output Voltage Swing           | $V_S = \pm 15\text{V}$ , $R_L = 10\text{ k}\Omega$                                                         | ±12   | ±14 |     | ±12    | ±14 |     | V             |
|                                | $R_L = 2\text{ k}\Omega$                                                                                   | ±10   | ±13 |     | ±10    | ±13 |     | V             |
| Input Voltage Range            | $V_S = \pm 15\text{V}$                                                                                     | ±12   |     |     | ±12    |     |     | V             |
| Common Mode Rejection Ratio    | $R_L \leq 10\text{ k}\Omega$                                                                               | 70    | 90  |     | 70     | 90  |     | dB            |
| Supply Voltage Rejection Ratio | $R_L \leq 10\text{ k}\Omega$                                                                               | 77    | 96  |     | 77     | 96  |     | dB            |

Note 1: The maximum junction temperature of the LM741 is 150°C, while that of the LM741C is 100°C. For operating at elevated temperatures, devices in the TO-5 package must be derated based on a thermal resistance of 150°C/W, junction to case.

Note 2: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 3: These specifications apply for  $V_S = \pm 15\text{V}$  and  $-55^\circ\text{C} \leq T_A \leq 125^\circ\text{C}$ , unless otherwise specified. With the LM741C, however, all specifications are limited to  $0^\circ\text{C} \leq T_A \leq 70^\circ\text{C}$  and  $V_S = \pm 15\text{V}$ .

# ORDERING INFORMATION

| Device     | Temperature Range | Package     |
|------------|-------------------|-------------|
| MC1741SG   | -55°C to +125°C   | Metal Can   |
| MC1741SU   | -55°C to +125°C   | Ceramic DIP |
| MC1741SCG  | 0°C to +70°C      | Metal Can   |
| MC1741SCP1 | 0°C to +70°C      | Plastic DIP |
| MC1741SCU  | 0°C to +70°C      | Ceramic DIP |

**MC1741S**  
**MC1741SC**

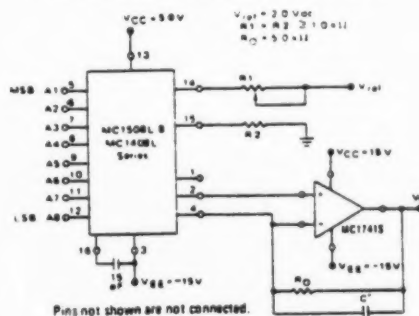
## HIGH SLEW-RATE INTERNALLY-COMPENSATED OPERATIONAL AMPLIFIER

The MC1741S/MC1741SC is functionally equivalent, pin compatible, and possesses the same ease of use as the popular MC1741 circuit, yet offers 20 times higher slew rate and power bandwidth. This device is ideally suited for D-to-A converters due to its fast settling time and high slew rate.

- High Slew Rate — 10 V/μs Guaranteed Minimum (for unity gain only)
- No Frequency Compensation Required
- Short-Circuit Protection
- Offset Voltage Null Capability
- Wide Common-Mode and Differential Voltage Ranges
- Low Power Consumption
- No Latch-Up

## OPERATIONAL AMPLIFIER SILICON MONOLITHIC INTEGRATED CIRCUIT

### TYPICAL APPLICATION OUTPUT CURRENT TO VOLTAGE TRANSFORMATION FOR A D-TO-A CONVERTER



Setting time to within 1/2 LSB ( $\pm 19.5$  mV) is approximately 40 μs from the time that all bits are switched.  
\*The value of C may be selected to minimize overshoot and ringing (C = 68 pF).

### G SUFFIX METAL PACKAGE CASE 601-02



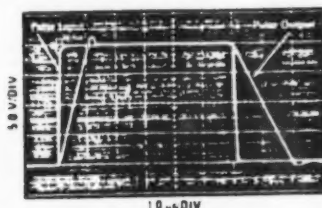
### Theoretical $V_0$

$$V_0 = \frac{V_{ref}}{R_1} (R_0) \left[ \frac{A_1}{2} + \frac{A_2}{4} + \frac{A_3}{8} + \frac{A_4}{16} + \frac{A_5}{32} + \frac{A_6}{64} + \frac{A_7}{128} + \frac{A_8}{256} \right]$$

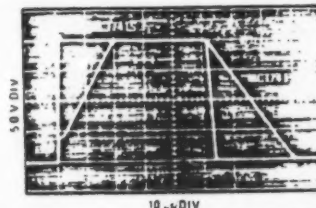
Adjust  $V_{ref}$ ,  $R_1$  or  $R_0$  so that  $V_0$  with all digital inputs at high level is equal to 9.961 volts

$$V_0 = \frac{2V}{1k} \left[ \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \frac{1}{32} + \frac{1}{64} + \frac{1}{128} + \frac{1}{256} \right] = 10V \left[ \frac{255}{256} \right] = 9.961V$$

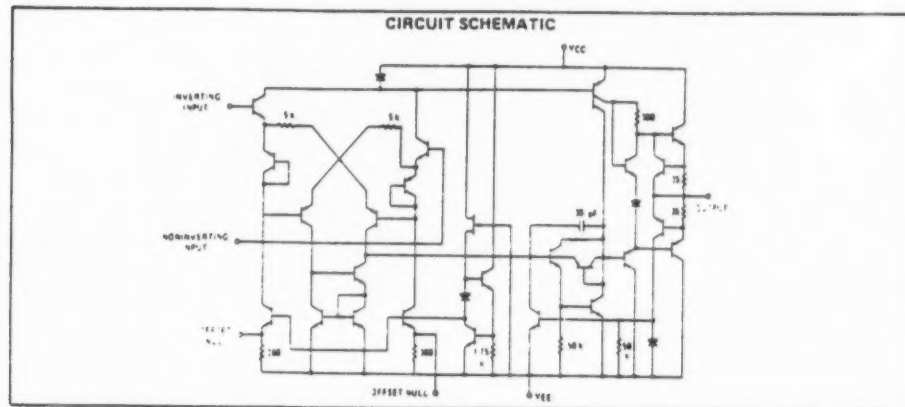
### MC1741S LARGE SIGNAL TRANSIENT RESPONSE



### STANDARD MC1741 vs MC1741S RESPONSE COMPARISON



# MC1741S, MC1741SC

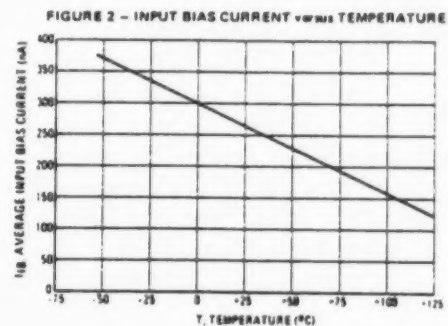
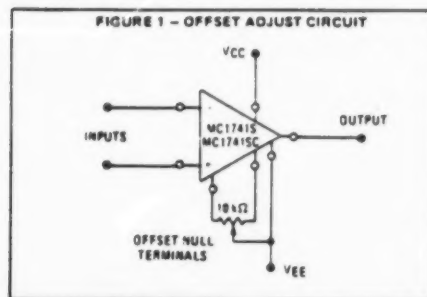


**MAXIMUM RATINGS** ( $T_A = +25^\circ\text{C}$  unless otherwise noted.)

| Rating                                       | Symbol               | Value       |             | Unit                 |
|----------------------------------------------|----------------------|-------------|-------------|----------------------|
|                                              |                      | MC1741SC    | MC1741S     |                      |
| Power Supply Voltage                         | $V_{CC}$<br>$V_{EE}$ | +18<br>-18  | +22<br>-22  | Vdc                  |
| Differential Input Signal Voltage            | $V_{ID}$             | $\pm 30$    |             | Volts                |
| Common-Mode Input Voltage Swing (See Note 1) | $V_{ICR}$            | $\pm 15$    |             | Volts                |
| Output Short-Circuit Duration (See Note 2)   | $t_1$                | Continuous  |             |                      |
| Power Dissipation (Package Limitation)       | $P_D$                |             |             |                      |
| Metal Package                                |                      | 680         |             | mW                   |
| Derate above $T_A = +25^\circ\text{C}$       |                      | 4.6         |             | mW/ $^\circ\text{C}$ |
| Plastic Dual In-Line Package                 |                      | 625         |             | mW                   |
| Derate above $T_A = +25^\circ\text{C}$       |                      | 5.0         |             | mW/ $^\circ\text{C}$ |
| Operating Ambient Temperature Range          | $T_A$                | 0 to +75    | -55 to +125 | $^\circ\text{C}$     |
| Storage Temperature Range                    | $T_{stg}$            |             |             | $^\circ\text{C}$     |
| Metal Package                                |                      | -65 to +150 |             |                      |
| Plastic Package                              |                      | -55 to +125 |             |                      |

Note 1. For supply voltages less than  $\pm 15$  Vdc, the absolute maximum input voltage is equal to the supply voltage.

Note 2. Supply voltage equal to or less than 15 Vdc.



# MC1741S, MC1741SC

ELECTRICAL CHARACTERISTICS ( $V_{CC} = +15$  Vdc,  $V_{EE} = -15$  Vdc,  $T_A = +25^\circ\text{C}$  unless otherwise noted.)

| Characteristic                                                                                                                                                                                               | Symbol             | MC1741S  |          |          | MC1741SC |          |          | Units      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|----------|----------|----------|----------|----------|----------|------------|
|                                                                                                                                                                                                              |                    | Min      | Typ      | Max      | Min      | Typ      | Max      |            |
| Power Bandwidth (See Figure 3)<br>$A_V = 1$ , $R_L = 2.0$ k $\Omega$ , THD = 5%, $V_O = 20$ V(p-p)                                                                                                           | BP                 | 150      | 200      | —        | 150      | 200      | —        | kHz        |
| Large-Signal Transient Response                                                                                                                                                                              |                    |          |          |          |          |          |          |            |
| Slew Rate (Figures 10 and 11)<br>$V(-)$ to $V(+)$                                                                                                                                                            | SR                 | 10       | 20       | —        | 10       | 20       | —        | V/ $\mu$ s |
| $V(+)$ to $V(-)$                                                                                                                                                                                             |                    | 10       | 12       | —        | 10       | 12       | —        |            |
| Settling Time (Figures 10 and 11)<br>(1% within 0.1%)                                                                                                                                                        | $t_{settle}$       | —        | 3.0      | —        | —        | 3.0      | —        | $\mu$ s    |
| Small-Signal Transient Response<br>(Gain = 1, $E_{in} = 20$ mV, see Figures 7 and 8)                                                                                                                         |                    |          |          |          |          |          |          |            |
| Rise Time                                                                                                                                                                                                    | $t_{RLH}$          | —        | 0.25     | —        | —        | 0.25     | —        | $\mu$ s    |
| Fall Time                                                                                                                                                                                                    | $t_{FHL}$          | —        | 0.25     | —        | —        | 0.25     | —        | $\mu$ s    |
| Propagation Delay Time                                                                                                                                                                                       | $t_{PLH}, t_{PHL}$ | —        | 0.25     | —        | —        | 0.25     | —        | $\mu$ s    |
| Overshoot                                                                                                                                                                                                    | OS                 | —        | 20       | —        | —        | 20       | —        | %          |
| Short-Circuit Output Currents                                                                                                                                                                                | $I_{OS}$           | $\pm 10$ | —        | $\pm 45$ | $\pm 10$ | —        | $\pm 45$ | mA         |
| Open-Loop Voltage Gain ( $R_L = 2.0$ k $\Omega$ ) (See Figure 4)<br>$V_O = \pm 10$ V, $T_A = +25^\circ\text{C}$                                                                                              | $A_{VOL}$          | 50,000   | 200,000  | —        | 20,000   | 100,000  | —        | —          |
| $V_O = \pm 10$ V, $T_A = T_{low}^*$ to $T_{high}^*$                                                                                                                                                          |                    | 25,000   | —        | —        | 15,000   | —        | —        | —          |
| Output Impedance ( $f = 20$ Hz)                                                                                                                                                                              | $Z_O$              | —        | 75       | —        | —        | 75       | —        | $\Omega$   |
| Input Impedance ( $f = 20$ Hz)                                                                                                                                                                               | $Z_i$              | 0.3      | 1.0      | —        | 0.3      | 1.0      | —        | M $\Omega$ |
| Output Voltage Swing<br>$R_L = 10$ k $\Omega$ , $T_A = T_{low}$ to $T_{high}$ (MC1741S only)<br>$R_L = 2.0$ k $\Omega$ , $T_A = +25^\circ\text{C}$<br>$R_L = 2.0$ k $\Omega$ , $T_A = T_{low}$ to $T_{high}$ | $V_O$              | $\pm 12$ | $\pm 14$ | —        | $\pm 12$ | $\pm 14$ | —        | $V_{pk}$   |
|                                                                                                                                                                                                              |                    | $\pm 10$ | $\pm 13$ | —        | $\pm 10$ | $\pm 13$ | —        |            |
|                                                                                                                                                                                                              |                    | $\pm 10$ | —        | —        | $\pm 10$ | —        | —        |            |
| Input Common-Mode Voltage Range<br>$T_A = T_{low}$ to $T_{high}$ (MC1741S)                                                                                                                                   | $V_{ICR}$          | $\pm 12$ | $\pm 13$ | —        | $\pm 12$ | $\pm 13$ | —        | $V_{pk}$   |
| Common-Mode Rejection Ratio ( $f = 20$ Hz)<br>$T_A = T_{low}$ to $T_{high}$ (MC1741S)                                                                                                                        | CMRR               | 70       | 90       | —        | 70       | 90       | —        | dB         |
| Input Bias Current (See Figure 2)<br>$T_A = +25^\circ\text{C}$ and $T_{high}$<br>$T_A = T_{low}$                                                                                                             | $I_{IB}$           | —        | 200      | 500      | —        | 200      | 500      | nA         |
|                                                                                                                                                                                                              |                    | —        | 500      | 1500     | —        | —        | 800      |            |
| Input Offset Current<br>$T_A = +25^\circ\text{C}$ and $T_{high}$<br>$T_A = T_{low}$                                                                                                                          | $ I_{IO} $         | —        | 30       | 200      | —        | 30       | 200      | nA         |
|                                                                                                                                                                                                              |                    | —        | —        | 500      | —        | —        | 300      |            |
| Input Offset Voltage ( $R_S = \leq 10$ k $\Omega$ )<br>$T_A = +25^\circ\text{C}$<br>$T_A = T_{low}$ to $T_{high}$                                                                                            | $ V_{IO} $         | —        | 1.0      | 5.0      | —        | 2.0      | 5.0      | mV         |
|                                                                                                                                                                                                              |                    | —        | —        | 6.0      | —        | —        | 7.5      |            |
| DC Power Consumption (See Figure 9)<br>(Power Supply = $\pm 15$ V, $V_O = 0$ )<br>$T_A = T_{low}$ to $T_{high}$                                                                                              | $P_C$              | —        | 50       | 85       | —        | 50       | 85       | mW         |
| Positive Voltage Supply Sensitivity<br>( $V_{EE}$ constant)<br>$T_A = T_{low}$ to $T_{high}$ on MC1741S                                                                                                      | PSS+               | —        | 2.0      | 100      | —        | 2.0      | 150      | $\mu$ V/V  |
| Negative Voltage Supply Sensitivity<br>( $V_{CC}$ constant) $T_A = T_{low}$ to $T_{high}$ on MC1741S                                                                                                         | PSS-               | —        | 10       | 150      | —        | 10       | 150      | $\mu$ V/V  |

\* $T_{low} = 0$  for MC1741SC  
=  $-55^\circ\text{C}$  for MC1741S

$T_{high} = +70^\circ\text{C}$  for MC1741SC  
=  $+125^\circ\text{C}$  for MC1741S





# OP-07

## ULTRA-LOW OFFSET VOLTAGE OPERATIONAL AMPLIFIER

### FEATURES

- Ultra-Low  $V_{OS}$  ..... 10 $\mu$ V
- Ultra-Low  $V_{OS}$  Drift ..... 0.2 $\mu$ V/ $^{\circ}$ C
- Ultra-Stable vs Time ..... 0.2 $\mu$ V/Month
- Ultra-Low Noise ..... 0.35 $\mu$ V $_{p-p}$
- No External Components Required
- Large Input Voltage Range .....  $\pm 14.0$ V
- Wide Supply Voltage Range .....  $\pm 3$ V to  $\pm 18$ V
- Fits 725, 108A/308A, 741, AD510 Sockets
- 125 $^{\circ}$ C Temperature Tested Dice

### GENERAL DESCRIPTION

The OP-07 Series represents a breakthrough in monolithic operational amplifier performance —  $V_{OS}$  of 10 $\mu$ V,  $TCV_{OS}$  of 0.2 $\mu$ V/ $^{\circ}$ C, and long-term stability of 0.2 $\mu$ V/month are achieved by a low-noise, bipolar input transistor amplifier circuit. Elimination of external components for offset nulling, frequency compensation, and device protection improves the system

MTBF and reduces cost. Excellent device interchangeability provides reduced system assembly time and eliminates field recalibrations.

True differential inputs with wide input voltage range and outstanding common-mode rejection provide excellent performance in high-noise environments and non-inverting applications. Low bias currents and extremely-high input impedances are maintained over the entire temperature range.

The OP-07 provides unparalleled performance for low noise, high-accuracy amplification of very low-level signals in transducer applications. Devices are available in chip form for use in hybrid circuitry. The OP-07 is a direct replacement for 725, 108A/308A\*, and OP-05 amplifiers. 741-types may be directly replaced by removing the 741's nulling potentiometer.

\*TO-99 package only. For Matched Dual see OP-207.

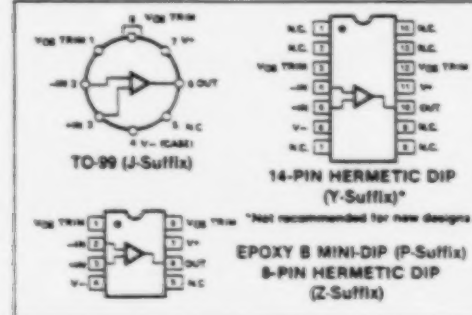
### ORDERING INFORMATION†

| T <sub>a</sub> = 25°C<br>V <sub>OS</sub> MAX<br>(μV) | PACKAGE        |                |         |                         | OPERATING<br>TEMPERATURE<br>RANGE |
|------------------------------------------------------|----------------|----------------|---------|-------------------------|-----------------------------------|
|                                                      | HERMETIC       |                |         | PLASTIC<br>DIP<br>8-PIN |                                   |
|                                                      | TO-98<br>8-PIN | DIP<br>8-PIN 1 | 14-PIN  |                         |                                   |
| 25                                                   | OP07AJ*        | OP07AZ*        | OP07AY* |                         | MIL                               |
| 75                                                   | OP07EJ         | OP07EZ         | OP07EY  | OP07EP                  | COM                               |
| 75                                                   | OP07J*         | OP07Z*         | OP07Y*  |                         | MIL                               |
| 150                                                  | OP07CJ         | OP07CZ         | OP07CY  | OP07CP                  | COM                               |
| 150                                                  | OP07DJ         |                |         | OP07DP                  | COM                               |

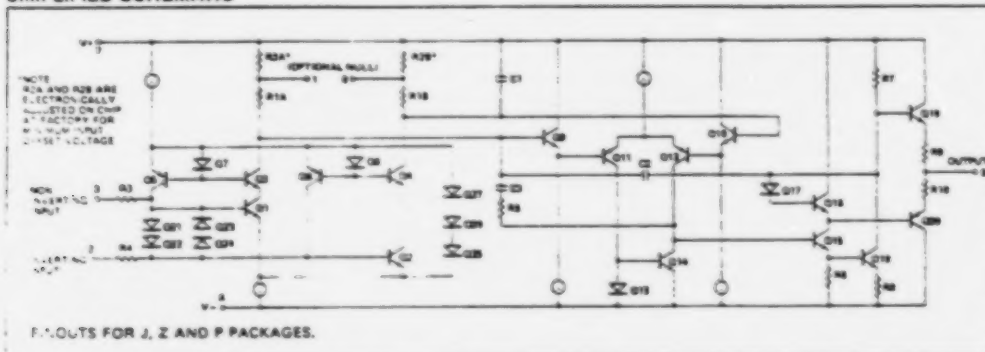
\* Also available with MIL-STD-883B processing. To order add/883 as a suffix to the part number.

† All listed parts are available with 160 hour burn-in. See Ordering Information, Section 2.

### PIN CONNECTIONS



### SIMPLIFIED SCHEMATIC



# OP-07 ULTRA-LOW OFFSET VOLTAGE OPERATIONAL AMPLIFIER

## ABSOLUTE MAXIMUM RATINGS

|                                             |                 |
|---------------------------------------------|-----------------|
| Supply Voltage                              | ±22V            |
| Internal Power Dissipation (Note 1)         | 500mW           |
| Differential Input Voltage                  | ±30V            |
| Input Voltage (Note 3)                      | ±22V            |
| Output Short Circuit Duration               | Indefinite      |
| Storage Temperature Range                   |                 |
| J, Y, and Z Packages                        | -65°C to +150°C |
| P Package                                   | -65°C to +125°C |
| Operating Temperature Range                 |                 |
| OP-07A, OP-07                               | -55 to +125°C   |
| OP-07E, OP-07C, OP-07D                      | 0°C to +70°C    |
| Lead Temperature Range (Soldering, 60 sec.) | 300°C           |
| DICE Junction Temperature $T_J$             | -65°C to +150°C |

## NOTES:

- See table for maximum ambient temperature rating and derating factor.
- Absolute maximum ratings apply to both packaged parts and dice, unless otherwise noted.
- For supply voltages less than ±22V, the absolute maximum input voltage is equal to the supply voltage.

| Package Type            | Maximum Ambient Temperature for Rating | Derate Above Maximum Ambient Temperature |
|-------------------------|----------------------------------------|------------------------------------------|
| TO-99 (J)               | 80°C                                   | 7 mW/°C                                  |
| 14-Pin Hermetic DIP (Y) | 100°C                                  | 10.0 mW/°C                               |
| 8-Pin Hermetic Dip (Z)  | 75°C                                   | 6.7 mW/°C                                |
| 8-Pin Plastic Dip (P)   | 38°C                                   | 5.8 mW/°C                                |

## ELECTRICAL CHARACTERISTICS

| PARAMETER                                | SYMBOL               | CONDITIONS                              | OP-07A |       |      | OP-07 |       |      | UNITS          |
|------------------------------------------|----------------------|-----------------------------------------|--------|-------|------|-------|-------|------|----------------|
|                                          |                      |                                         | MIN    | TYP   | MAX  | MIN   | TYP   | MAX  |                |
| Input Offset Voltage                     | $V_{OS}$             | (Note 1)                                | —      | 10    | 25   | —     | 30    | 75   | $\mu V$        |
| Long Term Input Offset Voltage Stability | $\Delta V_{OS}/Time$ | (Note 2)                                | —      | 0.2   | 1.0  | —     | 0.2   | 1.0  | $\mu V/Mo$     |
| Input Offset Current                     | $I_{OS}$             |                                         | —      | 0.3   | 2.0  | —     | 0.4   | 2.8  | nA             |
| Input Bias Current                       | $I_B$                |                                         | —      | ±0.7  | ±2.0 | —     | ±1.0  | ±3.0 | nA             |
| Input Noise Voltage                      | $e_{n,p}$            | 0.1Hz to 10kHz (Note 3)                 | —      | 0.35  | 0.6  | —     | 0.35  | 0.6  | $\mu V_{p,p}$  |
| Input Noise Voltage Density              | $e_n$                | $f_p = 10Hz$                            | —      | 10.3  | 18.0 | —     | 10.3  | 18.0 | $nV/\sqrt{Hz}$ |
|                                          |                      | $f_p = 100Hz$ (Note 3)                  | —      | 10.0  | 13.0 | —     | 10.0  | 13.0 |                |
|                                          |                      | $f_p = 1000Hz$                          | —      | 9.6   | 11.0 | —     | 9.6   | 11.0 |                |
| Input Noise Current                      | $i_{n,p}$            | 0.1Hz to 10kHz (Note 3)                 | —      | 14    | 30   | —     | 14    | 30   | $pA_{p,p}$     |
| Input Noise Current Density              | $i_n$                | $f_p = 10Hz$                            | —      | 0.32  | 0.80 | —     | 0.32  | 0.80 | $pA/\sqrt{Hz}$ |
|                                          |                      | $f_p = 100Hz$ (Note 3)                  | —      | 0.14  | 0.23 | —     | 0.14  | 0.23 |                |
|                                          |                      | $f_p = 1000Hz$                          | —      | 0.12  | 0.17 | —     | 0.12  | 0.17 |                |
| Input Resistance — Differential Mode     | $R_{id}$             | Note 4                                  | 30     | 80    | —    | 20    | 60    | —    | M $\Omega$     |
| Input Resistance — Common Mode           | $R_{icm}$            |                                         | —      | 200   | —    | —     | 200   | —    | G $\Omega$     |
| Input Voltage Range                      | $V_{IR}$             |                                         | ±13.0  | ±14.0 | —    | ±13.0 | ±14.0 | —    | V              |
| Common Mode Rejection Ratio              | CMRR                 | $V_{CM} = \pm 12V$                      | 110    | 126   | —    | 110   | 126   | —    | dB             |
| Power Supply Rejection Ratio             | PSRR                 | $V_S = 3V$ to $\pm 18V$                 | —      | 4     | 10   | —     | 4     | 10   | $\mu V/V$      |
| Large Signal Voltage Gain                | $A_{VO}$             | $R_L \geq 2k\Omega$ , $V_O = \pm 10V$   | 300    | 500   | —    | 200   | 500   | —    | V/V            |
|                                          |                      | $R_L \geq 500\Omega$ , $V_O = \pm 0.5V$ | 180    | 400   | —    | 150   | 400   | —    |                |
|                                          |                      | $V_S = \pm 3V$ (Note 3)                 |        |       |      |       |       |      |                |
| Output Voltage Swing                     | $V_O$                | $R_L \geq 10k\Omega$                    | ±12.5  | ±13.0 | —    | ±12.5 | ±13.0 | —    | V              |
|                                          |                      | $R_L \geq 2k\Omega$                     | ±12.0  | ±12.8 | —    | ±12.0 | ±12.8 | —    |                |
|                                          |                      | $R_L \geq 1k\Omega$                     | ±10.5  | ±12.0 | —    | ±10.5 | ±12.0 | —    |                |
| Slew Rate                                | SR                   | $R_L \geq 2k\Omega$ (Note 3)            | 0.1    | 0.3   | —    | 0.1   | 0.3   | —    | V/μs           |
| Closed Loop Bandwidth                    | BW                   | $A_{VOL} = 10$ (Note 3)                 | 0.4    | 0.6   | —    | 0.4   | 0.6   | —    | kHz            |
| Open Loop Output Resistance              | $R_O$                | $V_O = 0$ to $\pm 0$                    | —      | 60    | —    | —     | 60    | —    | $\Omega$       |
| Power Consumption                        | $P_S$                | $V_S = \pm 15V$ , No load               | —      | 75    | 120  | —     | 75    | 120  | mW             |
|                                          |                      | $V_S = \pm 3V$ , No load                | —      | 4     | 6    | —     | 4     | 6    |                |
| Offset Adjustment Range                  | $R_B$                | $R_B = 20k\Omega$                       | —      | ±4    | —    | —     | ±4    | —    | mV             |

## NOTES:

- OP-07A grade  $V_{OS}$  is measured one minute after application of power. For all other grades  $V_{OS}$  is measured approximately 0.5 seconds after application of power.
- Long Term Input Offset Voltage Stability refers to the averaged trend line of  $V_{OS}$  vs. Time over extended periods after the first 30 days of operation.
- Sample tested.
- Guaranteed by design.

Excluding the initial hour of operation, changes in  $V_{OS}$  during the first 30 operating days are typically  $\pm 2.5\mu V$  — refer to typical performance curves. Parameter is sample tested.

# OP-07 ULTRA-LOW OFFSET VOLTAGE OPERATIONAL AMPLIFIER

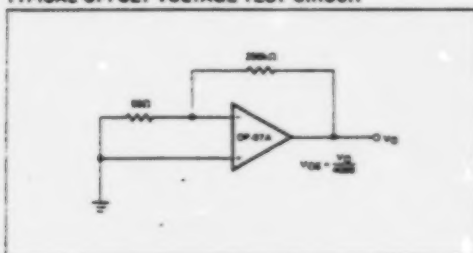
## ELECTRICAL CHARACTERISTICS at $V_S = \pm 15V$ , $-55^\circ C \leq T_A \leq +125^\circ C$ , unless otherwise noted.

| PARAMETER                                                | SYMBOL       | CONDITIONS                            | OP-07A     |            |           | OP-07      |            |           | UNITS            |
|----------------------------------------------------------|--------------|---------------------------------------|------------|------------|-----------|------------|------------|-----------|------------------|
|                                                          |              |                                       | MIN        | TYP        | MAX       | MIN        | TYP        | MAX       |                  |
| Input Offset Voltage                                     | $V_{OS}$     | (Note 1)                              | —          | 25         | 80        | —          | 80         | 200       | $\mu V$          |
| Average Input Offset Voltage Drift Without External Trim | $TCV_{OS}$   | (Note 2)                              | —          | 0.2        | 0.8       | —          | 0.3        | 1.3       | $\mu V/^\circ C$ |
| With External Trim                                       | $TCV_{OS}^*$ | $R_p = 20k\Omega$ (Note 2)            | —          | 0.2        | 0.8       | —          | 0.3        | 1.3       | $\mu V/^\circ C$ |
| Input Offset Current                                     | $I_{OS}$     |                                       | —          | 0.8        | 4.0       | —          | 1.2        | 5.8       | nA               |
| Average Input Offset Current Drift                       | $TCI_{OS}$   | (Note 2)                              | —          | 5          | 25        | —          | 8          | 50        | $pA/^\circ C$    |
| Input Bias Current                                       | $I_B$        |                                       | —          | $\pm 1.0$  | $\pm 4.0$ | —          | $\pm 2.0$  | $\pm 8.0$ | nA               |
| Average Input Bias Current Drift                         | $TCI_B$      | (Note 2)                              | —          | 8          | 25        | —          | 13         | 50        | $pA/^\circ C$    |
| Input Voltage Range                                      | IVR          |                                       | $\pm 13.0$ | $\pm 13.5$ | —         | $\pm 13.0$ | $\pm 13.5$ | —         | V                |
| Common Mode Rejection Ratio                              | CMRR         | $V_{CM} = \pm 13V$                    | 108        | 123        | —         | 106        | 123        | —         | dB               |
| Power Supply Rejection Ratio                             | PSRR         | $V_S = \pm 3V$ to $\pm 18V$           | —          | 5          | 20        | —          | 5          | 20        | $\mu V/V$        |
| Large Signal Voltage Gain                                | $A_{VO}$     | $R_L \geq 2k\Omega$ , $V_O = \pm 10V$ | 200        | 400        | —         | 190        | 400        | —         | V/mV             |
| Output Voltage Swing                                     | $V_O$        | $R_L \geq 2k\Omega$                   | $\pm 12.0$ | $\pm 12.6$ | —         | $\pm 12.0$ | $\pm 12.6$ | —         | V                |

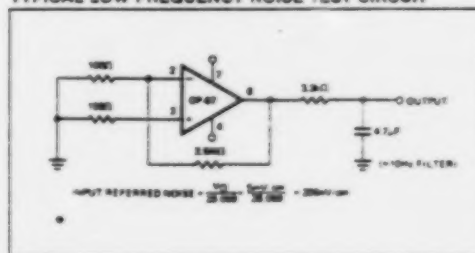
### NOTES:

- OP-07A grade  $V_{OS}$  is measured one minute after application of power. For all other grades  $V_{OS}$  is measured approximately 0.5 seconds after application of power.
- Sample tested.

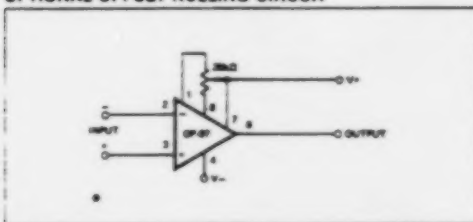
### TYPICAL OFFSET VOLTAGE TEST CIRCUIT



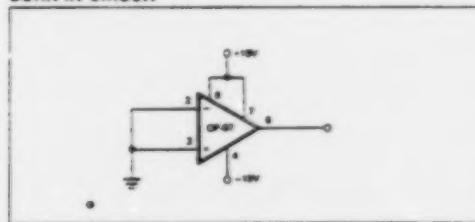
### TYPICAL LOW FREQUENCY NOISE TEST CIRCUIT



### OPTIONAL OFFSET NULLING CIRCUIT



### BURN-IN CIRCUIT



\*PINOUTS FOR P, J AND Z PACKAGES.

OP-07 ULTRA-LOW OFFSET VOLTAGE OPERATIONAL AMPLIFIER

ELECTRICAL CHARACTERISTICS at  $V_S = \pm 15V$ ,  $T_A = 25^\circ C$ , unless otherwise noted.

| PARAMETER                            | SYMBOL        | CONDITIONS                               | OP-07E     |            |           | OP-07C     |            |           | OP-07D     |            |          | UNITS             |
|--------------------------------------|---------------|------------------------------------------|------------|------------|-----------|------------|------------|-----------|------------|------------|----------|-------------------|
|                                      |               |                                          | MIN        | TYP        | MAX       | MIN        | TYP        | MAX       | MIN        | TYP        | MAX      |                   |
| Input Offset Voltage                 | $V_{OS}$      | (Note 1)                                 | —          | 30         | 75        | —          | 60         | 150       | —          | 60         | 150      | $\mu V$           |
| Long Term $V_{OS}$ Stability         | $V_{OS}/Time$ | (Note 2)                                 | —          | 0.3        | 1.5       | —          | 0.4        | 2.0       | —          | 0.5        | 3.0      | $\mu V/Mo$        |
| Input Offset Current                 | $I_{OS}$      |                                          | —          | 0.5        | 3.8       | —          | 0.8        | 6.0       | —          | 0.8        | 6.0      | nA                |
| Input Bias Current                   | $I_B$         |                                          | —          | $\pm 1.2$  | $\pm 4.0$ | —          | $\pm 1.8$  | $\pm 7.0$ | —          | $\pm 2.0$  | $\pm 12$ | nA                |
| Input Noise Voltage                  | $e_{n,p}$     | 0.1Hz to 10Hz (Note 3)                   | —          | 0.35       | 0.6       | —          | 0.38       | 0.65      | —          | 0.38       | 0.65     | $\mu V/\sqrt{Hz}$ |
|                                      |               | $f_s = 10Hz$                             | —          | 10.3       | 18.0      | —          | 10.5       | 20.0      | —          | 10.5       | 20.0     |                   |
| Input Noise Voltage Density          | $e_n$         | $f_s = 100Hz$ (Note 3)                   | —          | 10.0       | 13.0      | —          | 10.2       | 13.5      | —          | 10.3       | 13.5     | nV/ $\sqrt{Hz}$   |
|                                      |               | $f_s = 1000Hz$                           | —          | 9.8        | 11.0      | —          | 9.8        | 11.5      | —          | 9.8        | 11.5     |                   |
| Input Noise Current                  | $i_{n,p}$     | 0.1Hz to 10Hz (Note 3)                   | —          | 14         | 30        | —          | 15         | 35        | —          | 15         | 35       | pA/ $\sqrt{Hz}$   |
|                                      |               | $f_s = 10Hz$                             | —          | 0.32       | 0.80      | —          | 0.35       | 0.90      | —          | 0.35       | 0.90     |                   |
| Input Noise Current Density          | $i_n$         | $f_s = 100Hz$ (Note 3)                   | —          | 0.14       | 0.23      | —          | 0.15       | 0.27      | —          | 0.15       | 0.27     | pA/ $\sqrt{Hz}$   |
|                                      |               | $f_s = 1000Hz$                           | —          | 0.12       | 0.17      | —          | 0.13       | 0.18      | —          | 0.13       | 0.18     |                   |
| Input Resistance — Differential Mode | $R_{in}$      | (Note 4)                                 | 15         | 50         | —         | 8          | 33         | —         | 7          | 31         | —        | M $\Omega$        |
| Input Resistance — Common Mode       | $R_{inCM}$    |                                          | —          | 160        | —         | —          | 120        | —         | —          | 120        | —        | G $\Omega$        |
| Input Voltage Range (VIR)            |               |                                          | $\pm 13.0$ | $\pm 14.0$ | —         | $\pm 13.0$ | $\pm 14.0$ | —         | $\pm 13.0$ | $\pm 14.0$ | —        | V                 |
| Common Mode Rejection Ratio          | CMRR          | $V_{CM} = \pm 13V$                       | 106        | 123        | —         | 100        | 120        | —         | 94         | 110        | —        | dB                |
| Power Supply Rejection Ratio         | PSRR          | $V_S = \pm 3V$ to $\pm 18V$              | —          | 5          | 20        | —          | 7          | 32        | —          | 7          | 32       | $\mu V/V$         |
| Large Signal Voltage Gain            | $A_{vD}$      | $R_L \geq 2k\Omega$<br>$V_O = \pm 10V$   | 200        | 500        | —         | 120        | 400        | —         | 120        | 400        | —        | V/mV              |
|                                      |               | $R_L \geq 500\Omega$<br>$V_O = \pm 0.5V$ | 150        | 400        | —         | 100        | 400        | —         | —          | 400        | —        |                   |
|                                      |               | $V_S = \pm 3V$ (Note 3)                  |            |            |           |            |            |           |            |            |          |                   |
|                                      |               |                                          |            |            |           |            |            |           |            |            |          |                   |
| Output Voltage Swing                 | $V_O$         | $R_L \geq 10k\Omega$                     | $\pm 12.5$ | $\pm 13.0$ | —         | $\pm 12.0$ | $\pm 13.0$ | —         | $\pm 12.0$ | $\pm 13.0$ | —        | V                 |
|                                      |               | $R_L \geq 2k\Omega$                      | $\pm 12.0$ | $\pm 12.8$ | —         | $\pm 11.5$ | $\pm 12.8$ | —         | $\pm 11.5$ | $\pm 12.8$ | —        |                   |
|                                      |               | $R_L \geq 1k\Omega$                      | $\pm 10.5$ | $\pm 12.0$ | —         | —          | $\pm 12.0$ | —         | —          | $\pm 12.0$ | —        |                   |
| Slewing Rate                         | SR            | $R_L \geq 2k\Omega$ (Note 3)             | 0.1        | 0.3        | —         | 0.1        | 0.3        | —         | 0.1        | 0.3        | —        | V/ $\mu s$        |
| Closed Loop Bandwidth                | GB            | $A_{vCL} = +10$ (Note 3)                 | 0.4        | 0.8        | —         | 0.4        | 0.8        | —         | 0.4        | 0.8        | —        | MHz               |
| Open Loop Output Resistance          | $R_O$         | $V_O = 0, I_O = 0$                       | —          | 60         | —         | —          | 60         | —         | —          | 60         | —        | $\Omega$          |
| Power Consumption                    | $P_d$         | $V_S = \pm 15V$ , No load                | —          | 75         | 120       | —          | 80         | 150       | —          | 80         | 150      | mW                |
|                                      |               | $V_S = \pm 3V$ , No load                 | —          | 4          | 8         | —          | 4          | 8         | —          | 4          | 8        |                   |
| Offset Adjustment Range              |               | $R_S = 20k\Omega$                        | —          | $\pm 4$    | —         | —          | $\pm 4$    | —         | —          | $\pm 4$    | —        | mV                |

NOTES:

1. Input offset voltage measurements are performed by automated test equipment approximately 0.5 seconds after application of power.
2. Long Term Input Offset Voltage Stability refers to the averaged trend line of  $V_{OS}$  vs. Time over extended periods after the first 30 days of

operation. Excluding the initial hour of operation, changes in  $V_{OS}$  during the first 30 operating days are typically  $2.5 \mu V$  — refer to typical performance curves. Parameter is sample tested.

3. Sample tested.
4. Guaranteed by design.

OP-07 ULTRA-LOW OFFSET VOLTAGE OPERATIONAL AMPLIFIER

ELECTRICAL CHARACTERISTICS at  $V_S = \pm 15V$ ,  $0^\circ C \leq T_A \leq +70^\circ C$ , unless otherwise noted.

| PARAMETER                                                | SYMBOL           | CONDITIONS                             | OP-07E     |            |           | OP-07C     |            |           | OP-07D     |            |          | UNITS            |
|----------------------------------------------------------|------------------|----------------------------------------|------------|------------|-----------|------------|------------|-----------|------------|------------|----------|------------------|
|                                                          |                  |                                        | MIN        | TYP        | MAX       | MIN        | TYP        | MAX       | MIN        | TYP        | MAX      |                  |
| Input Offset Voltage                                     | $V_{OS}$         | (Note 1)                               | —          | 45         | 130       | —          | 85         | 250       | —          | 85         | 250      | $\mu V$          |
| Average Input Offset Voltage Drift Without External Trim | $TCV_{OS}$       | (Note 2)                               | —          | 0.3        | 1.3       | —          | 0.5        | 1.8       | —          | 0.7        | 2.5      | $\mu V/^\circ C$ |
| With External Trim                                       | $TCV_{OS\Delta}$ | $R_D = 20k\Omega$ (Note 2)             | —          | 0.3        | 1.3       | —          | 0.4        | 1.8       | —          | 0.7        | 2.5      | $\mu V/^\circ C$ |
| Input Offset Current                                     | $I_{OS}$         |                                        | —          | 0.9        | 5.3       | —          | 1.8        | 8.0       | —          | 1.8        | 8.0      | nA               |
| Average Input Offset Current Drift                       | $TCI_{OS}$       | (Note 2)                               | —          | 8          | 35        | —          | 12         | 50        | —          | 12         | 50       | $pA/^\circ C$    |
| Input Bias Current                                       | $I_B$            |                                        | —          | $\pm 1.5$  | $\pm 5.5$ | —          | $\pm 2.2$  | $\pm 9.0$ | —          | $\pm 3.0$  | $\pm 14$ | nA               |
| Average Input Bias Current Drift                         | $TCI_B$          | (Note 2)                               | —          | 13         | 35        | —          | 18         | 50        | —          | 18         | 50       | $pA/^\circ C$    |
| Input Voltage Range                                      | IVR              |                                        | $\pm 13.0$ | $\pm 13.5$ | —         | $\pm 13.0$ | $\pm 13.5$ | —         | $\pm 13.0$ | $\pm 13.5$ | —        | V                |
| Common Mode Rejection Ratio                              | CMRR             | $V_{CM} = \pm 13V$                     | 103        | 123        | —         | 97         | 120        | —         | 94         | 106        | —        | dB               |
| Power Supply Rejection Ratio                             | PSRR             | $V_S = \pm 3V$ to $\pm 18V$            | —          | 7          | 32        | —          | 10         | 51        | —          | 10         | 51       | $\mu V/V$        |
| Large Signal Voltage Gain                                | $A_{VO}$         | $R_L \geq 2k\Omega$<br>$V_O = \pm 10V$ | 180        | 450        | —         | 100        | 400        | —         | 100        | 400        | —        | V/mV             |
| Output Voltage Swing                                     | $V_O$            | $R_L \geq 2k\Omega$                    | $\pm 12.0$ | $\pm 12.6$ | —         | $\pm 11.0$ | $\pm 12.6$ | —         | $\pm 11.0$ | $\pm 12.6$ | —        | V                |

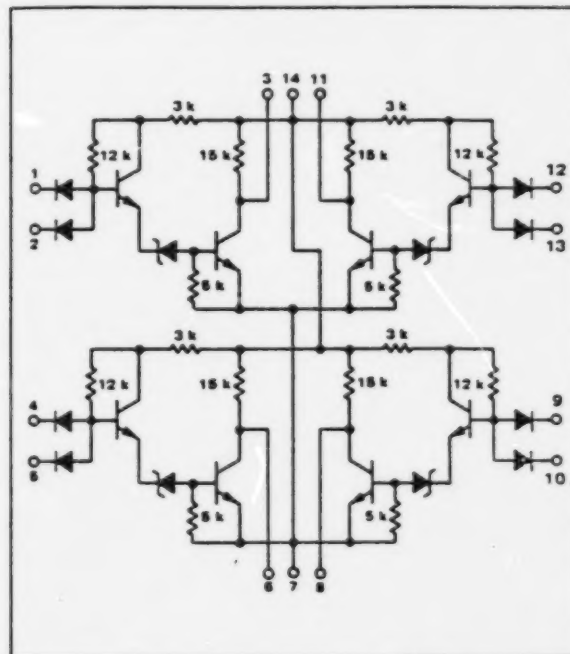
NOTES:

1. Input offset voltage measurements are performed by automated test equipment approximately 0.5 seconds after application of power.
2. Sample tested.

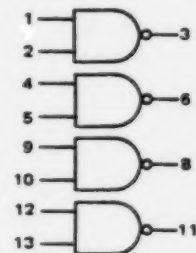
QUAD 2-INPUT  
"NAND" GATE  
(Passive Pullup)

MHTL MC660 series

MC668



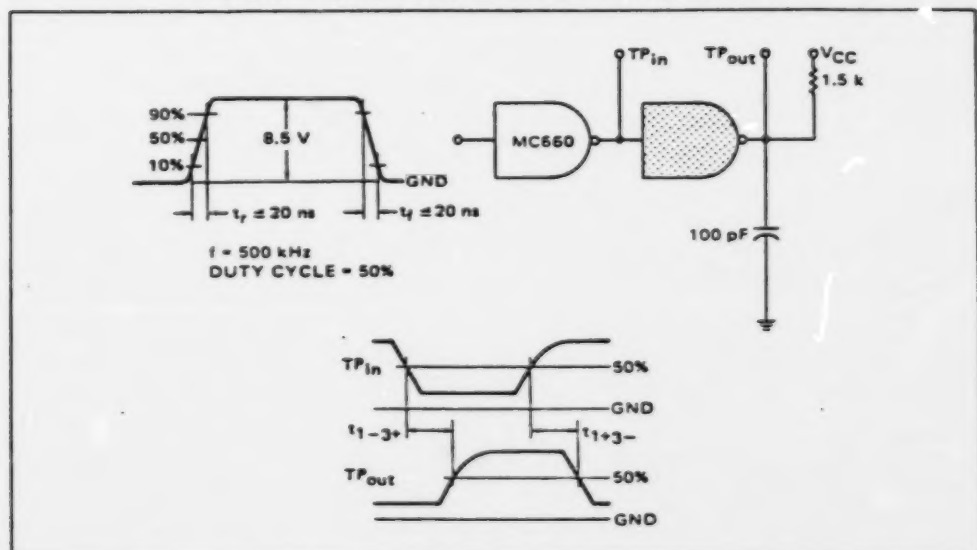
This device consists of four 2-input NAND gates with passive output pull-up.



Positive Logic:  $3 = 1 \cdot 2$

Input Loading Factor = 1  
Output Loading Factor = 10  
Propagation Delay Time = 125 ns typ  
Typical Total Power Dissipation  
Inputs High = 176 mW typ/pkg  
Inputs Low = 52 mW typ/pkg

SWITCHING TIME TEST CIRCUIT AND WAVEFORMS





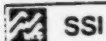
## ELECTRICAL CHARACTERISTICS

Test procedures are shown for only one gate.  
The other gates are tested in the same manner.

| TEST CURRENT/VOLTAGE VALUES (All Temperatures)     |  |                 |  |                 |  |                 |  |                 |  |                  |  |                  |  |                  |  |                  |  |                              |  |
|----------------------------------------------------|--|-----------------|--|-----------------|--|-----------------|--|-----------------|--|------------------|--|------------------|--|------------------|--|------------------|--|------------------------------|--|
| mA                                                 |  |                 |  |                 |  |                 |  |                 |  | Volts            |  |                  |  |                  |  |                  |  |                              |  |
| I <sub>OL</sub>                                    |  | I <sub>OH</sub> |  | V <sub>IL</sub> |  | V <sub>IH</sub> |  | V <sub>F</sub>  |  | V <sub>CEX</sub> |  | V <sub>CC</sub>  |  | V <sub>CCL</sub> |  | V <sub>CCH</sub> |  | Gnd                          |  |
| 12.0                                               |  | -0.03           |  | 6.50            |  | 8.50            |  | 1.5             |  | 16.0             |  | 15.0             |  | 14.0             |  | 16.0             |  |                              |  |
| TEST CURRENT/VOLTAGE APPLIED TO PINS LISTED BELOW: |  |                 |  |                 |  |                 |  |                 |  |                  |  |                  |  |                  |  |                  |  |                              |  |
|                                                    |  | I <sub>OL</sub> |  | I <sub>OH</sub> |  | V <sub>IL</sub> |  | V <sub>IH</sub> |  | V <sub>F</sub>   |  | V <sub>CEX</sub> |  | V <sub>CC</sub>  |  | V <sub>CCL</sub> |  | V <sub>CCH</sub>             |  |
|                                                    |  | 3               |  | -               |  | 1, 2            |  | -               |  | -                |  | -                |  | 14               |  | -                |  | 7                            |  |
|                                                    |  | -               |  | 3               |  | 1               |  | -               |  | -                |  | -                |  | 2                |  | 14               |  | ↑                            |  |
|                                                    |  | -               |  | 3               |  | 2               |  | -               |  | -                |  | -                |  | 1                |  | 14               |  | 1, 3, 7                      |  |
|                                                    |  | -               |  | -               |  | -               |  | -               |  | -                |  | -                |  | -                |  | -                |  | 14                           |  |
|                                                    |  | -               |  | -               |  | -               |  | -               |  | -                |  | -                |  | -                |  | -                |  | 2, 7                         |  |
|                                                    |  | -               |  | -               |  | -               |  | -               |  | -                |  | -                |  | -                |  | -                |  | 1, 7                         |  |
|                                                    |  | -               |  | -               |  | -               |  | -               |  | -                |  | 3, 14            |  | -                |  | -                |  | 1, 7                         |  |
|                                                    |  | -               |  | -               |  | -               |  | -               |  | 1                |  | -                |  | -                |  | -                |  | 7                            |  |
|                                                    |  | -               |  | -               |  | -               |  | 2               |  | 1                |  | -                |  | -                |  | -                |  | 7                            |  |
|                                                    |  | -               |  | -               |  | -               |  | -               |  | -                |  | -                |  | -                |  | -                |  | 1, 2, 4, 5, 7, 9, 10, 12, 13 |  |
|                                                    |  | -               |  | -               |  | -               |  | -               |  | -                |  | -                |  | -                |  | -                |  | 14                           |  |
|                                                    |  | -               |  | -               |  | -               |  | -               |  | -                |  | -                |  | -                |  | -                |  | 14                           |  |
|                                                    |  | Pulse In        |  | Pulse Out       |  |                 |  |                 |  |                  |  |                  |  |                  |  |                  |  |                              |  |
|                                                    |  | 1               |  | 3               |  |                 |  |                 |  |                  |  |                  |  |                  |  |                  |  | 7                            |  |
|                                                    |  | 1               |  | 3               |  |                 |  |                 |  |                  |  |                  |  |                  |  |                  |  | 7                            |  |

| TEST LIMITS                        |  |       |     |       |       |       |       |      |  |
|------------------------------------|--|-------|-----|-------|-------|-------|-------|------|--|
|                                    |  | -30°C |     | +25°C |       | +75°C |       | Unit |  |
| Pin Under Test                     |  | Min   | Max | Min   | Max   | Min   | Max   |      |  |
| Output Voltage                     |  | 3     | 1.5 | -     | 1.5   | -     | 1.5   | Vdc  |  |
| V <sub>OL</sub>                    |  | 3     | -   | 12.5  | -     | 12.5  | -     | ↑    |  |
| V <sub>OH</sub>                    |  | 3     | -   | 12.5  | -     | 12.5  | -     | ↑    |  |
| Short-Circuit Current              |  | 3     | -   | -0.6  | -1.5  | -0.6  | -1.5  | mAdc |  |
| Reverse Current                    |  | 1     | -   | -     | 2.0   | -     | 2.0   | μAde |  |
|                                    |  | 2     | -   | -     | 2.0   | -     | 2.0   | μAde |  |
| Output Leakage Current             |  | 3     | -   | -     | 100   | -     | 100   | μAde |  |
| Forward Current                    |  | 1     | -   | -     | -1.20 | -     | -1.20 | mAde |  |
|                                    |  | 2     | -   | -     | -1.20 | -     | -1.20 | mAde |  |
| Power Drain Current (Total Device) |  | 14    | -   | -     | 6.0   | -     | -     | mAde |  |
|                                    |  | 14    | -   | -     | 20.   | -     | -     | mAde |  |
| Switching Times                    |  | 3     | -   | -     | 250   | -     | -     | ns   |  |
|                                    |  | 3     | -   | -     | 100   | -     | -     | ns   |  |

Pins not listed are left open.



## DM54/DM74121, LS221 One Shots

## Electrical Characteristics over recommended operating free-air temperature range (unless otherwise noted)

| Electrical Characteristics |                                             |                                               |  |                         |         |          |         |         |      | over recommended operating free-air temperature range (unless otherwise noted) |  |  |  |  |  |  |  |  |  |
|----------------------------|---------------------------------------------|-----------------------------------------------|--|-------------------------|---------|----------|---------|---------|------|--------------------------------------------------------------------------------|--|--|--|--|--|--|--|--|--|
| Parameter                  |                                             | Conditions                                    |  | DM54/74                 |         |          | DM54/74 |         |      | Units                                                                          |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | 121                     |         |          | LS221   |         |      |                                                                                |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | Min                     | Typ (1) | Max      | Min     | Typ (1) | Max  |                                                                                |  |  |  |  |  |  |  |  |  |
| V <sub>T+</sub>            | Positive-Going Threshold Voltage at A Input | V <sub>CC</sub> = Min                         |  |                         | 1.4     | 2        |         | 1.0     | 2    | V                                                                              |  |  |  |  |  |  |  |  |  |
| V <sub>T-</sub>            | Negative-Going Threshold Voltage at A Input | V <sub>CC</sub> = Min                         |  | DM54                    | 0.8     | 1.4      |         | 0.8     | 1.0  | V                                                                              |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | DM74                    | 0.8     | 1.4      |         | 0.8     | 1.0  |                                                                                |  |  |  |  |  |  |  |  |  |
| V <sub>T+</sub>            | Positive-Going Threshold Voltage at B Input | V <sub>CC</sub> = Min                         |  |                         | 1.55    | 2        |         | 1.0     | 2    | V                                                                              |  |  |  |  |  |  |  |  |  |
| V <sub>T-</sub>            | Negative-Going Threshold Voltage at B Input | V <sub>CC</sub> = Min                         |  | DM54                    | 0.8     | 1.35     |         | 0.8     | 0.9  | V                                                                              |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | DM74                    | 0.8     | 1.35     |         | 0.8     | 0.9  |                                                                                |  |  |  |  |  |  |  |  |  |
| V <sub>I</sub>             | Input Clamp Voltage                         | V <sub>CC</sub> = Min                         |  | I <sub>I</sub> = -12 mA |         |          |         | -1.5    |      | V                                                                              |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | I <sub>I</sub> = -18 mA |         |          |         |         | -1.5 |                                                                                |  |  |  |  |  |  |  |  |  |
| I <sub>OH</sub>            | High Level Output Current                   |                                               |  |                         |         |          |         | -400    |      | μA                                                                             |  |  |  |  |  |  |  |  |  |
| V <sub>OH</sub>            | High Level Output Voltage                   | V <sub>CC</sub> = Min                         |  | DM54                    | 2.4     | 3.4      |         | 2.5     | 3.4  | V                                                                              |  |  |  |  |  |  |  |  |  |
|                            |                                             | I <sub>OH</sub> = -400 μA                     |  | DM74                    | 2.4     | 3.4      |         | 2.7     | 3.4  |                                                                                |  |  |  |  |  |  |  |  |  |
| I <sub>OL</sub>            | Low Level Output Current                    |                                               |  | DM54                    |         |          | 16      |         | 4    | mA                                                                             |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | DM74                    |         |          | 16      |         | 8    |                                                                                |  |  |  |  |  |  |  |  |  |
| V <sub>OL</sub>            | Low Level Output Voltage                    | V <sub>CC</sub> = Min                         |  | I <sub>OL</sub> = 4 mA  |         |          |         |         | 0.25 | 0.4                                                                            |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | I <sub>OL</sub> = 8 mA  |         | DM74     |         |         | 0.35 | 0.5                                                                            |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | I <sub>OL</sub> = 16 mA |         |          |         | 0.2     | 0.4  |                                                                                |  |  |  |  |  |  |  |  |  |
| I <sub>I</sub>             | Input Current at Maximum Input Voltage      | V <sub>CC</sub> = Max                         |  | V <sub>I</sub> = 5.5 V  |         |          |         | 1       |      | mA                                                                             |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | V <sub>I</sub> = 7 V    |         |          |         |         | 0.1  |                                                                                |  |  |  |  |  |  |  |  |  |
| I <sub>IH</sub>            | High Level Input Current                    | V <sub>CC</sub> = Max                         |  | V <sub>O</sub> = 2.4 V  |         | A1 or A2 |         | 40      |      | μA                                                                             |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  |                         |         | B        |         | 80      |      |                                                                                |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | V <sub>I</sub> = 2.7-V  |         | All      |         |         |      | 20                                                                             |  |  |  |  |  |  |  |  |  |
| I <sub>IL</sub>            | Low Level Input Current                     | V <sub>CC</sub> = Max, V <sub>I</sub> = 0.4 V |  | A1 or A2                |         |          |         | -1.6    |      | -4                                                                             |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | B                       |         |          |         | -3.2    |      | -8                                                                             |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | Clear                   |         |          |         | N/A     |      | -0.8                                                                           |  |  |  |  |  |  |  |  |  |
| I <sub>OS</sub>            | Short Circuit Output Current                | V <sub>CC</sub> = Max (2)                     |  | DM54                    | -20     | -55      | -20     |         | -100 | mA                                                                             |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | DM74                    | -18     | -55      | -20     |         | -100 |                                                                                |  |  |  |  |  |  |  |  |  |
| I <sub>CC</sub>            | Supply Current                              | V <sub>CC</sub> = Max                         |  | Quiescent               |         | 13       | 25      | 4.7     | 11   | mA                                                                             |  |  |  |  |  |  |  |  |  |
|                            |                                             |                                               |  | Triggered               |         | 23       | 40      | 19      | 27   |                                                                                |  |  |  |  |  |  |  |  |  |

Note 1: All typical values are V<sub>CC</sub> = 5 V, T<sub>A</sub> = 25°C

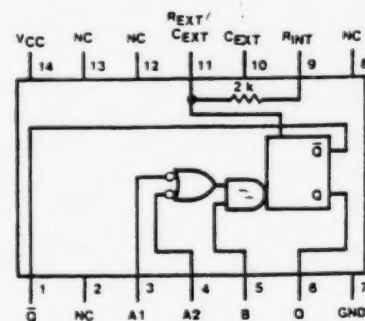
Note 2: Not more than one output should be shorted at a time, and for DM54, LS221, DM74, LS221, duration of short circuit should not exceed one second

121 One Shots

Truth Table

| Inputs |    |   | Outputs |           |
|--------|----|---|---------|-----------|
| A1     | A2 | B | Q       | $\bar{Q}$ |
| L      | X  | H | L       | H         |
| X      | L  | H | L       | H         |
| X      | X  | L | L       | H         |
| H      | H  | X | L       | H         |
| H      | H  | H | L       | H         |
| H      | H  | H | L       | H         |
| L      | X  | L | L       | H         |
| X      | L  | L | L       | H         |

L = low  
H = high  
X = does not matter



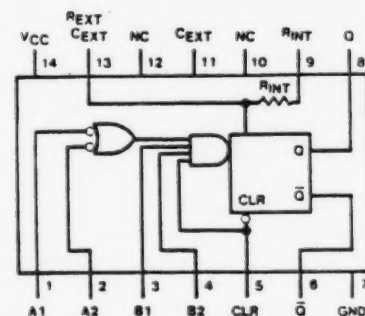
54121 (J,W); 74121 (N)

See page 5-44

122 Retriggerable One Shots with Clear

Truth Table

| Clear | Inputs |    |    |    | Outputs |           |
|-------|--------|----|----|----|---------|-----------|
|       | A1     | A2 | B1 | B2 | Q       | $\bar{Q}$ |
| L     | X      | X  | X  | X  | L       | H         |
| X     | X      | H  | X  | X  | L       | H         |
| X     | X      | X  | L  | X  | L       | H         |
| X     | X      | X  | X  | L  | L       | H         |
| X     | L      | X  | H  | H  | L       | H         |
| H     | L      | X  | L  | H  | L       | H         |
| H     | L      | X  | H  | L  | L       | H         |
| H     | X      | L  | L  | H  | L       | H         |
| H     | X      | L  | H  | L  | L       | H         |
| H     | H      | L  | H  | H  | L       | H         |
| H     | H      | L  | L  | H  | L       | H         |
| H     | H      | H  | L  | H  | L       | H         |
| H     | H      | H  | H  | L  | L       | H         |
| H     | H      | H  | H  | H  | L       | H         |
| L     | L      | X  | H  | H  | L       | H         |
| L     | X      | L  | H  | H  | L       | H         |



54LS122 (J,W); 74LS122 (N)

See page 5-46

Notes:  $\square$  = one high-level pulse,  $\square$  = one low-level pulse.  
To use the internal timing resistor of 54121, 74121, connect R<sub>INT</sub> to VCC.  
An external timing capacitor may be connected between CEXT and REXT/CEXT (positive).  
For accurate repeatable pulse widths, connect an external resistor between REXT/CEXT and VCC with R<sub>INT</sub> open-circuited.  
To obtain variable pulse widths, connect external variable resistance between R<sub>INT</sub> or REXT/CEXT and VCC.



**MM54C00/MM74C00 Quad 2-Input NAND Gate**  
**MM54C02/MM74C02 Quad 2-Input NOR Gate**  
**MM54C04/MM74C04 Hex Inverter**  
**MM54C10/MM74C10 Triple 3-Input NAND Gate**  
**MM54C20/MM74C20 Dual 4-Input NAND Gate**

**general description**

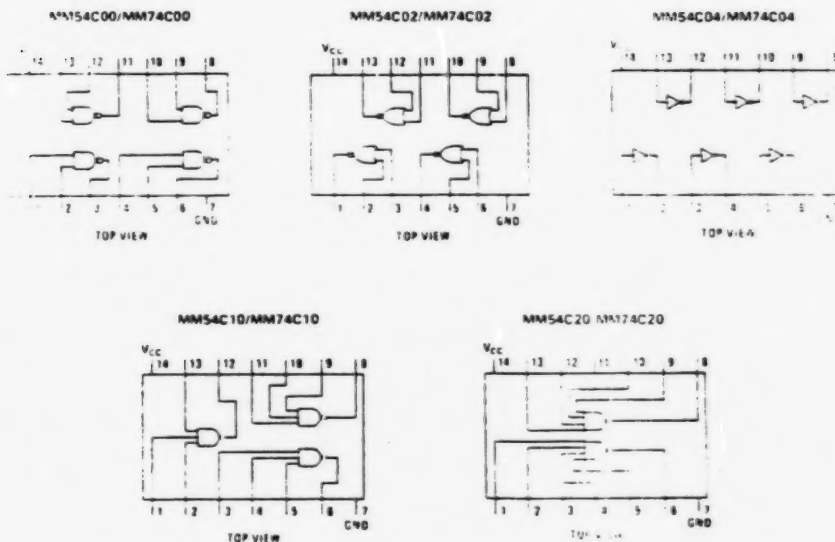
These logic gates employ complementary MOS (CMOS) to achieve wide power supply operating range, low power consumption, high noise immunity and symmetric controlled rise and fall times. With features such as this the 54C/74C logic family is close to ideal for use in digital systems. Function and pin out compatibility with series 54/74 devices minimizes design time for those designers already familiar with the standard 54/74 logic family.

All inputs are protected from damage due to static discharge by diode clamps to  $V_{CC}$  and GND.

**features**

- Wide supply voltage range      3.0V to 15V
- Guaranteed noise margin      1.0V
- High noise immunity       $0.45 V_{CC}$  typ
- Low power consumption      10 nW/package typ
- Low power TTL compatibility      fan out of 2 driving 74L

**connection diagrams**



**absolute maximum ratings** (Note 1)

|                                          |                          |
|------------------------------------------|--------------------------|
| Voltage at Any Pin                       | -0.3V to $V_{CC} + 0.3V$ |
| Operating Temperature Range              |                          |
| 54C                                      | -55°C to +125°C          |
| 74C                                      | -40°C to +85°C           |
| Storage Temperature Range                | -65°C to +150°C          |
| Operating $V_{CC}$ Range                 | 3.0V to 15V              |
| Maximum $V_{CC}$ Voltage                 | 18V                      |
| Package Dissipation                      | 500 mW                   |
| Lead Temperature (Soldering, 10 seconds) | 300°C                    |

**dc electrical characteristics**

Min/max limits apply across the guaranteed temperature range unless otherwise noted.

| PARAMETER                                                           | CONDITIONS                                                                    | MIN                              | TYP   | MAX        | UNITS   |
|---------------------------------------------------------------------|-------------------------------------------------------------------------------|----------------------------------|-------|------------|---------|
| <b>CMOS TO CMOS</b>                                                 |                                                                               |                                  |       |            |         |
| Logical "1" Input Voltage ( $V_{IH}$ )                              | $V_{CC} = 5.0V$<br>$V_{CC} = 10V$                                             | 3.5<br>8.0                       |       |            | V       |
| Logical "0" Input Voltage ( $V_{IL}$ )                              | $V_{CC} = 5.0V$<br>$V_{CC} = 10V$                                             |                                  |       | 1.5<br>2.0 | V       |
| Logical "1" Output Voltage ( $V_{OH}$ )                             | $V_{CC} = 5.0V, I_O = -10\mu A$<br>$V_{CC} = 10V, I_O = -10\mu A$             | 4.5<br>9.0                       |       |            | V       |
| Logical "0" Output Voltage ( $V_{OL}$ )                             | $V_{CC} = 5.0V, I_O = +10\mu A$<br>$V_{CC} = 10V, I_O = +10\mu A$             |                                  |       | 1.5<br>1.0 | V       |
| Logical "1" Input Current ( $I_{IH}$ )                              | $V_{CC} = 15V, V_{IH} = 15V$                                                  |                                  | 0.005 |            | $\mu A$ |
| Logical "0" Input Current ( $I_{IL}$ )                              | $V_{CC} = 15V, V_{IL} = 0V$                                                   | 1.0                              | 0.005 |            | $\mu A$ |
| Supply Current ( $I_{CC}$ )                                         | $V_{CC} = 15V$                                                                |                                  | 0.01  | 1.5        | $\mu A$ |
| <b>LOW POWER TO CMOS</b>                                            |                                                                               |                                  |       |            |         |
| Logical "1" Input Voltage ( $V_{IH}$ )                              | 54C, $V_{CC} = 4.5V$<br>74C, $V_{CC} = 4.75V$                                 | $V_{CC} - 1.5$<br>$V_{CC} - 1.5$ |       |            | V       |
| Logical "0" Input Voltage ( $V_{IL}$ )                              | 54C, $V_{CC} = 4.5V$<br>74C, $V_{CC} = 4.75V$                                 |                                  |       | 0.9<br>1.0 | V       |
| Logical "1" Output Voltage ( $V_{OH}$ )                             | 54C, $V_{CC} = 4.5V, I_O = 10\mu A$<br>74C, $V_{CC} = 4.75V, I_O = 10\mu A$   | 4.4<br>4.4                       |       |            | V       |
| Logical "0" Output Voltage ( $V_{OL}$ )                             | 54C, $V_{CC} = 4.5V, I_O = +10\mu A$<br>74C, $V_{CC} = 4.75V, I_O = +10\mu A$ |                                  |       | 0.4<br>0.4 | V       |
| <b>CMOS TO LOW POWER</b>                                            |                                                                               |                                  |       |            |         |
| Logical "1" Input Voltage ( $V_{IH}$ )                              | 54C, $V_{CC} = 4.5V$<br>74C, $V_{CC} = 4.75V$                                 | 4.0<br>4.0                       |       |            | V       |
| Logical "0" Input Voltage ( $V_{IL}$ )                              | 54C, $V_{CC} = 4.5V$<br>74C, $V_{CC} = 4.75V$                                 |                                  |       | 1.0<br>1.0 | V       |
| Logical "1" Output Voltage ( $V_{OH}$ )                             | 54C, $V_{CC} = 4.5V, I_O = 360\mu A$<br>74C, $V_{CC} = 4.75V, I_O = 360\mu A$ | 2.4<br>2.4                       |       |            | V       |
| Logical "0" Output Voltage ( $V_{OL}$ )                             | 54C, $V_{CC} = 4.5V, I_O = 360\mu A$<br>74C, $V_{CC} = 4.75V, I_O = 360\mu A$ |                                  |       | 0.4<br>0.4 | V       |
| <b>OUTPUT DRIVE (See 54C/74C Family Characteristics Data Sheet)</b> |                                                                               |                                  |       |            |         |
| Output Source Current ( $I_{source}$ )                              | $V_{CC} = 5.0V, V_{OL} = 0V$<br>$T_A = 25^\circ C, V_{OUT} = 0V$              | 1.75                             |       |            | mA      |
| Output Source Current ( $I_{source}$ )                              | $V_{CC} = 10V, V_{OL} = 0V$<br>$T_A = 25^\circ C, V_{OUT} = 0V$               | 8.0                              |       |            | mA      |
| Output Sink Current ( $I_{sink}$ )                                  | $V_{CC} = 5.0V, V_{OH} = 5.0V$<br>$T_A = 25^\circ C, V_{OUT} = V_{CC}$        | 1.75                             |       |            | mA      |
| Output Sink Current ( $I_{sink}$ )                                  | $V_{CC} = 10V, V_{OH} = 10V$<br>$T_A = 25^\circ C, V_{OUT} = V_{CC}$          | 8.0                              |       |            | mA      |

# INTERMIL

# ICM7555/7556

# CMOS

## General Purpose Timers

### FEATURES

- Exact equivalent in most cases for SE/NE555/556 or the 355.
- Low Supply Current — 80 $\mu$ A Typ. (ICM7555) 160 $\mu$ A Typ. (ICM7556)
- Extremely low trigger, threshold and reset currents - 20pA Typical
- High speed operation - 500 kHz guaranteed
- Wide operation supply voltage range guaranteed 2 to 18 volts
- Normal Reset function - No crowbaring of supply during output transition.
- Can be used with higher impedance timing elements than regular 555/6 for longer RC time constants.
- Timing from microseconds through hours
- Operates in both astable and monostable modes
- Adjustable duty cycle
- High output source/sink driver can drive TTL/CMOS
- Typical temperature stability of 0.005% per °C at 25°C
- Outputs have very low offsets, HI and LO

### GENERAL DESCRIPTION

The ICM7555/6 are CMOS RC timers providing significantly improved performance over the standard SE/NE555/6 and 355 timers, while at the same time being direct replacements for those devices in most applications. Improved parameters include low supply current, wide operating supply voltage range, low THRESHOLD, TRIGGER and RESET currents, no crowbaring of the supply current during output transitions, higher frequency performance and no requirement to decouple CONTROL VOLTAGE for stable operation.

Specifically, the ICM7555/6 are stable controllers capable of producing accurate time delays or frequencies. The ICM7556 is a dual ICM7555, with the two timers operating independently of each other, sharing only V<sup>+</sup> and GND. In the one shot mode, the pulse width of each circuit is precisely controlled by one external resistor and capacitor. For astable operation as an oscillator, the free running frequency and the duty cycle are both accurately controlled by two external resistors and one capacitor. Unlike the regular bipolar 555/6 devices, the CONTROL VOLTAGE terminal need not be decoupled with a capacitor. The circuits are triggered and reset on falling negative waveforms, and the output inverter can source or sink currents large enough to drive TTL loads, or provide minimal offsets to drive CMOS loads.

6

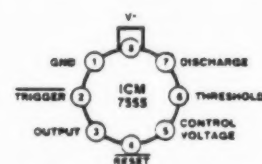
### APPLICATIONS

- Precision Timing
- Pulse Generation
- Sequential Timing
- Time Delay Generation
- Pulse Width Modulation
- Pulse Position Modulation
- Missing Pulse Detector

### ORDERING INFORMATION

| ORDER PART NUMBER | TEMPERATURE RANGE | PACKAGE             |
|-------------------|-------------------|---------------------|
| ICM7555IPA        | -20 to +85°C      | 8 Lead MiniDip      |
| ICM7555ITY        | -20 to +85°C      | TO-98 Can           |
| ICM7555MTY        | -55 to +125°C     | TO-98 Can           |
| ICM7556IPD        | -20 to +85°C      | 14 Lead Plastic DIP |
| ICM7556MJD        | -55 to +125°C     | 14 Lead CERDIP      |
| ICM7555/D         |                   | DICE                |
| ICM7556/D         |                   | DICE                |

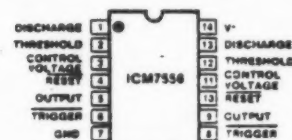
### PIN CONFIGURATIONS (Top View)



(OUTLINE DRAWING TO-99)



(OUTLINE DRAWING PA)



(OUTLINE DRAWING JD, PD)



# ICM7555/ICM7556

INTERSIL

## ABSOLUTE MAXIMUM RATINGS NOTE 1)

|                                           |                 |                                              |
|-------------------------------------------|-----------------|----------------------------------------------|
| Supply Voltage                            | .....           | +18 Volts                                    |
| Input Voltage                             | Trigger         | ..... $\leq V^- - 0.3V$ to $\geq V^- - 0.3V$ |
|                                           | Threshold       | .....                                        |
|                                           | Reset           | .....                                        |
| Output Current                            | Control Voltage | ..... 100mA                                  |
| Power Dissipation <sup>2)</sup>           | ICM7556         | ..... 300mW                                  |
|                                           | ICM7555         | ..... 200mW                                  |
| Operating Temperature Range <sup>2)</sup> |                 |                                              |
|                                           | ICM7555IPA      | ..... -20°C to +85°C                         |
|                                           | ICM7555ITY      | ..... -20°C to +85°C                         |
|                                           | ICM7556IPD      | ..... -20°C to +85°C                         |
|                                           | ICM7555MTY      | ..... -55°C to +125°C                        |
|                                           | ICM7556MJD      | ..... -55°C to +125°C                        |
| Storage Temperature                       | .....           | -65°C to +150°C                              |
| Lead Temperature (Soldering 60 Seconds)   | .....           | +300°C                                       |

NOTE: Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## OPERATING CHARACTERISTICS ( $T_A = 25^\circ\text{C}$ , $V^- = +2$ to $+15$ Volts unless other specified)

| PARAMETER                    | SYMBOL     | TEST CONDITIONS                                                                     | VALUE      |                |                   | UNITS                 |
|------------------------------|------------|-------------------------------------------------------------------------------------|------------|----------------|-------------------|-----------------------|
|                              |            |                                                                                     | MIN        | TYP            | MAX               |                       |
| Supply Voltage               | $V^+$      | -20°C $\leq T_A \leq +70^\circ\text{C}$<br>-55°C $\leq T_A \leq +125^\circ\text{C}$ | 2<br>3     |                | 18<br>16          | V<br>V                |
| Supply Current <sup>3)</sup> | $I^-$      | ICM7555 $V^+ = 2V$                                                                  |            | 60             | 200               | $\mu\text{A}$         |
|                              |            | $V^+ = 18V$                                                                         |            | 120            | 300               | $\mu\text{A}$         |
|                              |            | ICM7556 $V^+ = 2V$                                                                  |            | 120            | 400               | $\mu\text{A}$         |
|                              |            | $V^+ = 18V$                                                                         |            | 240            | 600               | $\mu\text{A}$         |
| Timing Error                 |            | $R_A, R_B = 1k$ to $100k$ ,<br>$C = 0.1\mu\text{F}$<br>Note 4                       |            |                |                   |                       |
| Initial Accuracy             |            | $V^+ = 5V$                                                                          |            | 2.0            | 5.0               | %                     |
| Drift with Temperature       |            | $V^+ = 10V$<br>$V^+ = 15V$                                                          |            | 50             | 200<br>300<br>600 | ppm/ $^\circ\text{C}$ |
| Drift with Supply Voltage    |            | $V^- = 5V$                                                                          |            | 1.0            | 3.0               | %/V                   |
| Threshold Voltage            | $V_{TH}$   | $V^+$                                                                               | 0.63       | 0.66           | 0.67              | $V^+$                 |
| Trigger Voltage              | $V_{TRIG}$ | $V^+$                                                                               | 0.29       | 0.33           | 0.34              | $V^+$                 |
| Trigger Current              | $I_{TRIG}$ | $V^- = 18V$<br>$V^+ = 5V$<br>$V^+ = 2V$                                             |            | 50<br>10<br>1  |                   | pA<br>pA<br>pA        |
| Threshold Current            | $I_{TH}$   | $V^- = 18V$<br>$V^+ = 5V$<br>$V^+ = 2V$                                             |            | 50<br>10<br>1  |                   | pA<br>pA<br>pA        |
| Reset Current                | $I_{RST}$  | $V_{RESET} = \text{Ground}$<br>$V^+ = 18V$<br>$V^+ = 5V$<br>$V^+ = 2V$              |            | 100<br>20<br>2 |                   | pA<br>pA<br>pA        |
| Reset Voltage                | $V_{RST}$  | $V^+ = 18V$<br>$V^+ = 2V$                                                           | 0.4<br>0.4 | 0.7<br>0.7     | 1.0<br>1.0        | V<br>V                |
| Control Voltage Lead         | $V_{CV}$   | $V^+$                                                                               | 0.62       | 0.66           | 0.67              | $V^+$                 |
| Output Voltage Drop          | $V_O$      | Output Lo- $V^+ = 18V$ $I_{SINK} = 3.2mA$                                           |            | 0.1            | 0.4               | V                     |
|                              |            | $V^+ = 5V$ $I_{SINK} = 3.2mA$                                                       |            | 0.15           | 0.4               | V                     |
|                              |            | Output Hi- $V^+ = 18V$ $I_{SOURCE} = 1.0mA$                                         | 17 25      | 17.8           |                   | V                     |
|                              |            | $V^+ = 5V$ $I_{SOURCE} = 1.0mA$                                                     | 4.0        | 4.5            |                   | V                     |
| Rise Time of Output          | $t_r$      | $R_L = 10M\Omega$ $C_L = 10pF$ $V^+ = 5V$                                           | 35         | 40             | 75                | ns                    |
| Fall Time of Output          | $t_f$      | $R_L = 10M\Omega$ $C_L = 10pF$ $V^+ = 5V$                                           | 35         | 40             | 75                | ns                    |
| Guaranteed Max Osc Freq      | $f_{max}$  | Astable Operation                                                                   | 500        |                |                   | kHz                   |

### NOTES:

1. Due to the SCR structure inherent in the CMOS process used to fabricate these devices, connecting any terminal to a voltage greater than  $V^- + 1.5V$  or less than  $V^- - 0.3V$  may cause destructive latchup. For this reason it is recommended that no inputs from external sources not deriving from the same power supply be applied to the device before its power supply is established. In multiple systems, the supply of the ICM7555/6 must be turned on first.
2. Junction temperatures should not exceed  $135^\circ\text{C}$  and the power dissipation must be limited to 20mW at  $125^\circ\text{C}$ . Below  $125^\circ\text{C}$  power dissipation may be increased to 300mW at  $25^\circ\text{C}$ . Derating factor is approximately  $3mW/^\circ\text{C}$  ICM7556 or  $2mW/^\circ\text{C}$  ICM7555.
3. The supply current value is essentially independent of the TRIGGER, THRESHOLD and RESET voltages.
4. Parameter is not 100% tested. Majority of all units meet this specification.



**National  
Semiconductor**

## Voltage Regulators

### LM109/LM209/LM309 5-Volt Regulator

#### General Description

The LM109 series are complete 5 V regulators fabricated on a single silicon chip. They are designed for local regulation on digital logic cards, eliminating the distribution problems associated with single-point regulation. The devices are available in two standard transistor packages. In the solid-kovar TO-5 header, it can deliver output currents in excess of 200 mA, if adequate heat sinking is provided. With the TO-3 power package, the available output current is greater than 1 A.

The regulators are essentially blowout proof. Current limiting is included to limit the peak output current to a safe value. In addition, thermal shutdown is provided to keep the IC from overheating. If internal dissipation becomes too great, the regulator will shut down to prevent excessive heating.

Considerable effort was expended to make these devices easy to use and to minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response somewhat. Input bypassing is needed, however, if the regulator is

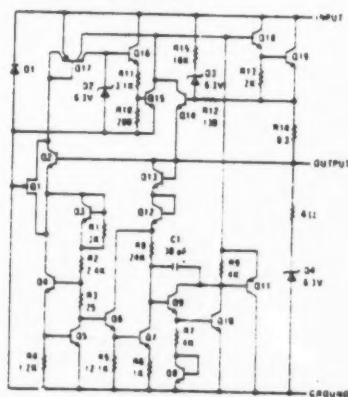
located very far from the filter capacitor of the power supply. Stability is also achieved by methods that provide very good rejection of load or line transients as are usually seen with TTL logic.

Although designed primarily as a fixed-voltage regulator, the output of the LM109 series can be set to voltages above 5 V, as shown below. It is also possible to use the circuits as the control element in precision regulators, taking advantage of the good current-handling capability and the thermal overload protection.

#### Features

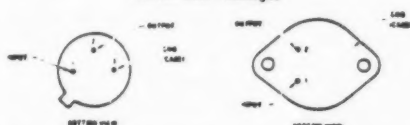
- Specified to be compatible, worst case, with TTL and DTL
- Output current in excess of 1 A
- Internal thermal overload protection
- No external components required

#### Schematic Diagram



#### Connection Diagrams

##### Metal Can Packages

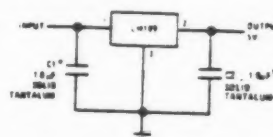


Order Number LM109H, LM209H  
or LM309H  
See Package H03A

Order Number LM109K STEEL,  
LM209K STEEL, LM309K STEEL  
See Package K02A  
Order Number LM309K (ALUMINUM)  
See Package KC02A

#### Typical Application

##### Fixed 5V Regulator

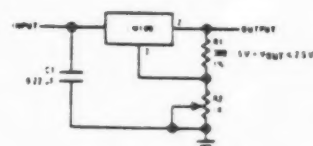


\* Required if regulator is located more than 4" from power supply filter capacitor.

† Although no output capacitor is needed for stability, it does improve transient response. C2 should be used whenever long wires are used to connect to the load, or when transient response is critical.

NOTE: Pin 3 electrically connected to case.

##### Adjustable Output Regulator



## Absolute Maximum Ratings

|                                          |                    |
|------------------------------------------|--------------------|
| Input Voltage                            | 35 V               |
| Power Dissipation                        | Internally Limited |
| Operating Junction Temperature Range     |                    |
| LM109                                    | -55°C to +150°C    |
| LM209                                    | -25°C to +150°C    |
| LM309                                    | 0°C to +125°C      |
| Storage Temperature Range                | -65°C to +150°C    |
| Lead Temperature (Soldering, 10 seconds) | 300°C              |

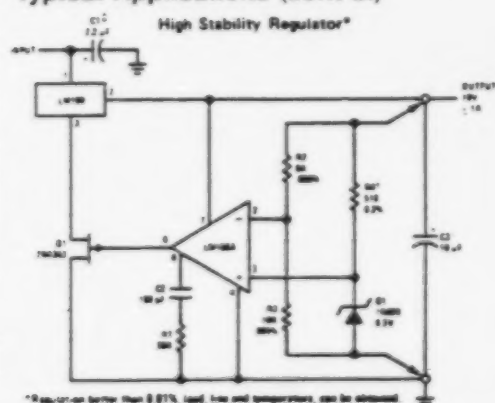
## Electrical Characteristics

| PARAMETER                               | CONDITIONS                                                                                 | LM109/LM209 |      |     | LM309 |      |      | UNITS                     |
|-----------------------------------------|--------------------------------------------------------------------------------------------|-------------|------|-----|-------|------|------|---------------------------|
|                                         |                                                                                            | MIN         | TYP  | MAX | MIN   | TYP  | MAX  |                           |
| Output Voltage                          | $T_j = 25^\circ\text{C}$                                                                   | 4.7         | 5.05 | 5.3 | 4.8   | 5.05 | 5.2  | V                         |
| Line Regulation                         | $T_j = 25^\circ\text{C}$ ,<br>$7\text{V} < V_{IN} < 25\text{V}$                            |             | 4.0  | 50  |       | 4.0  | 50   | mV                        |
| Load Regulation                         | $T_j = 25^\circ\text{C}$                                                                   |             |      |     |       |      |      |                           |
| TO-5 Package                            | $5\text{mA} < I_{OUT} < 0.5\text{A}$                                                       |             | 15   | 50  |       | 15   | 50   | mV                        |
| TO-3 Package                            | $5\text{mA} < I_{OUT} < 1.5\text{A}$                                                       |             | 15   | 100 |       | 15   | 100  | mV                        |
| Output Voltage                          | $7\text{V} < V_{IN} < 25\text{V}$ ,<br>$5\text{mA} < I_{OUT} < I_{MAX}$ ,<br>$P < P_{MAX}$ | 4.6         |      | 5.4 | 4.75  |      | 5.25 | V                         |
| Quiescent Current                       | $7\text{V} < V_{IN} < 25\text{V}$                                                          |             | 5.2  | 10  |       | 5.2  | 10   | mA                        |
| Quiescent Current Change                | $7\text{V} < V_{IN} < 25\text{V}$ ,<br>$5\text{mA} < I_{OUT} < I_{MAX}$                    |             |      | 0.5 |       |      | 0.5  | mA                        |
|                                         |                                                                                            |             |      | 0.8 |       |      | 0.8  | mA                        |
| Output Noise Voltage                    | $T_A = 25^\circ\text{C}$ ,<br>$10\text{Hz} < f < 100\text{kHz}$                            |             | 40   |     |       | 40   |      | $\mu\text{V}$             |
| Long Term Stability                     |                                                                                            |             |      | 10  |       |      | 20   | mV                        |
| Ripple Rejection                        | $T_j = 25^\circ\text{C}$                                                                   | 50          |      |     | 50    |      |      | dB                        |
| Thermal Resistance,<br>Junction to Case | (Note 2)                                                                                   |             |      |     |       |      |      |                           |
| TO-5 Package                            |                                                                                            |             | 15   |     |       | 15   |      | $^\circ\text{C}/\text{W}$ |
| TO-3 Package                            |                                                                                            |             | 2.5  |     |       | 2.5  |      | $^\circ\text{C}/\text{W}$ |

Note 1: Unless otherwise specified, these specifications apply  $-55^\circ\text{C} < T_j < +150^\circ\text{C}$  for the LM109,  $-25^\circ\text{C} < T_j < +150^\circ\text{C}$  for the LM209, and  $0^\circ\text{C} < T_j < +125^\circ\text{C}$  for the LM309.  $V_{IN} = 10\text{V}$ , and  $I_{OUT} = 0.1\text{A}$  for the TO-39 package or  $I_{OUT} = 0.5\text{A}$  for the TO-3 package. For the TO-39 package  $I_{MAX} = 0.2\text{A}$  and  $P_{MAX} = 2.0\text{W}$ . For the TO-3 package,  $I_{MAX} = 1.0\text{A}$  and  $P_{MAX} = 20\text{W}$ .

Note 2: Without a heat sink, the thermal resistance of the TO-39 package is about  $150^\circ\text{C}/\text{W}$  while that of the TO-3 package is approximately  $35^\circ\text{C}/\text{W}$ . With a heat sink, the effective thermal resistance can only approach the values specified, depending on the efficiency of the sink.

## Typical Applications (cont'd.)

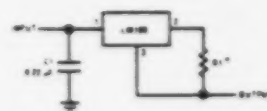


\* Regulation better than 0.01% load, line and temperature, can be obtained.

\* Output current limit may be adjusted to eliminate thermal drift.

See also text.

## Current Regulator



\* Determine output current. If wirewound resistor is used, bypass with  $0.1\mu\text{F}$ .

National  
Semiconductor

## Voltage Regulators

LM320L/LM320ML Series  
3-Terminal Negative Regulators

## General Description

The LM320L/LM320ML series of 3-terminal negative voltage regulators features fixed output voltages of -5V, -12V, and -15V, with output current capabilities in excess of 100 mA, for the LM320L series, and 250 mA for the LM320ML series. These devices were designed using the latest computer techniques for optimizing the packaged IC thermal/electrical performance. The LM320L/LM320ML series, even when combined with a minimum output compensation capacitor of 0.1  $\mu$ F, exhibits an excellent transient response, a maximum line regulation of 0.07%  $V_{O}/V$ , and a maximum load regulation of 0.01%  $V_{O}/mA$ .

The LM320L/LM320ML series also includes, as self-protection circuitry: safe operating area circuitry for output transistor power dissipation limiting, a temperature independent short circuit current limit for peak output current limiting, and a thermal shutdown circuit to prevent excessive junction temperature. Although designed primarily as fixed voltage regulators, these devices may be combined with simple external circuitry for boosted and/or adjustable voltages and currents. The LM320L series is available in the 3-lead TO-92 package, and the LM320ML series is available in the 3-lead TO-202 package.

For output voltages other than -5V, -12V and -15V, the LM137 series provides an output voltage range from -1.2V to -47V.

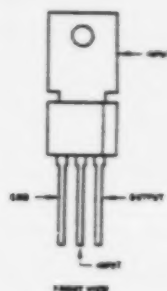
## Features

- Preset output voltage error is less than  $\pm 5\%$  over load, line and temperature
- LM320L is specified at an output current of 100 mA
- LM320ML is specified at an output current of 250 mA
- Internal short-circuit, thermal and safe operating area protection
- Easily adjustable to higher output voltages
- Maximum line regulation less than 0.07%  $V_{O}/V$
- Maximum load regulation less than 0.01%  $V_{O}/mA$
- Easily compensated with a small 0.1  $\mu$ F output capacitor

| DEVICE  | PACKAGE | RATED<br>POWER<br>DISSIPATION | DESIGN<br>OUTPUT<br>CURRENT |
|---------|---------|-------------------------------|-----------------------------|
| LM320ML | TO-202  | 7.5W                          | 0.25A                       |
| LM320L  | TO-92   | 0.6W                          | 0.1A                        |

## Connection Diagrams

TO-202 Power Package (P)



Order Numbers:

LM320MLP-5.0  
LM320MLP-12  
LM320MLP-15

See Package P03A

For Tab Band TO-202

Order Numbers:

LM320MLP-5.0 TB  
LM320MLP-12 TB  
LM320MLP-15 TB

See Package P03E

TO-92 Plastic Package (Z)



Order Numbers:

LM320LZ-5.0  
LM320LZ-12  
LM320LZ-15

See Package Z03A

## Absolute Maximum Ratings

|                                               |                    |
|-----------------------------------------------|--------------------|
| Input Voltage                                 |                    |
| $V_{OUT} = -5V, 12V$ and $15V$                | -35V               |
| Internal Power Dissipation<br>(Notes 1 and 3) | Internally Limited |
| Operating Temperature Range                   | 0°C to +70°C       |
| Maximum Junction Temperature                  | +125°C             |
| Storage Temperature Range                     |                    |
| Molded TO-92                                  | -55°C to +150°C    |
| Molded TO-202                                 | -65°C to +150°C    |
| Lead Temperature<br>(Soldering, 10 seconds)   | 300°C              |

## Electrical Characteristics LM320ML

(Note 2)  $T_A = 0^\circ\text{C}$  to  $+70^\circ\text{C}$  unless otherwise noted.

| OUTPUT VOLTAGE                                             |                                                                                                               | -5V                                               |     |       | -12V                                  |     |       | -15V                                |       |        | UNITS         |
|------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|---------------------------------------------------|-----|-------|---------------------------------------|-----|-------|-------------------------------------|-------|--------|---------------|
| INPUT VOLTAGE (unless otherwise noted)                     |                                                                                                               | -18V                                              |     |       | -17V                                  |     |       | -20V                                |       |        |               |
| PARAMETER                                                  | CONDITIONS                                                                                                    | MIN                                               | TYP | MAX   | MIN                                   | TYP | MAX   | MIN                                 | TYP   | MAX    |               |
| $V_O$ Output Voltage                                       | $T_J = 25^\circ\text{C}$ , $I_O = 250\text{ mA}$                                                              | -5.2                                              | -5  | -4.8  | -12.5                                 | -12 | -11.5 | -15.8                               | -15   | -14.4  | V             |
|                                                            | $1\text{ mA} \leq I_O \leq 250\text{ mA}$                                                                     | -5.25                                             |     | -4.75 | -12.6                                 |     | -11.4 | -15.75                              |       | -14.25 |               |
|                                                            | $(V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}})$                                                     | $(-20 \leq V_{\text{IN}} \leq -7.5)$              |     |       | $(-27 \leq V_{\text{IN}} \leq -14.8)$ |     |       | $(-30 \leq V_{\text{IN}} \leq -18)$ |       |        |               |
| $\Delta V_O$ Line Regulation                               | $T_J = 25^\circ\text{C}$ , $I_O = 250\text{ mA}$<br>$(V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}})$ |                                                   |     | 50    |                                       |     | 40    |                                     |       | 40     | mV            |
| $\Delta V_O$ Load Regulation                               | $T_J = 25^\circ\text{C}$<br>$1\text{ mA} \leq I_O \leq 250\text{ mA}$                                         |                                                   |     | 50    |                                       |     | 120   |                                     |       | 150    | mV            |
| $\Delta V_O$ Long Term Stability                           | $I_O = 250\text{ mA}$                                                                                         |                                                   | 20  |       |                                       | 40  |       |                                     | 60    |        | mV/yr         |
| $I_Q$ Quiescent Current                                    | $I_O = 250\text{ mA}$                                                                                         |                                                   | 2   | 6     |                                       | 2   | 6     |                                     | 2     | 6      | mA            |
| $\Delta I_Q$ Quiescent Current Change                      | $1\text{ mA} \leq I_O \leq 250\text{ mA}$                                                                     |                                                   |     | 0.3   |                                       |     | 0.3   |                                     |       | 0.3    | mA            |
|                                                            | $I_O = 250\text{ mA}$                                                                                         |                                                   |     | 0.25  |                                       |     | 0.25  |                                     |       | 0.25   |               |
|                                                            | $(V_{\text{MIN}} \leq V_{\text{IN}} \leq V_{\text{MAX}})$                                                     | $(-20 \leq V_{\text{IN}} \leq -7.5)$              |     |       | $(-27 \leq V_{\text{IN}} \leq -14.8)$ |     |       | $(-30 \leq V_{\text{IN}} \leq -18)$ |       |        |               |
| $V_n$ Output Noise Voltage                                 | $T_J = 25^\circ\text{C}$ , $I_O = 250\text{ mA}$<br>$f = 10\text{ Hz} - 10\text{ kHz}$                        |                                                   |     | 40    |                                       |     | 100   |                                     |       | 120    | $\mu\text{V}$ |
| $\frac{\Delta V_{\text{IN}}}{\Delta V_O}$ Ripple Rejection | $T_J = 25^\circ\text{C}$ , $I_O = 250\text{ mA}$<br>$f = 120\text{ Hz}$                                       |                                                   | 54  |       |                                       | 56  |       |                                     | 54    |        | dB            |
| Input Voltage Required to Maintain Line Regulation         |                                                                                                               | $T_J = 25^\circ\text{C}$<br>$I_O = 250\text{ mA}$ |     |       | -7.3                                  |     | -14.8 |                                     | -17.7 |        | V             |

Note 1: Thermal resistance of the TO-202 Package (P) without a heat sink is  $12^\circ\text{C/W}$  junction to case and  $70^\circ\text{C/W}$  case to ambient.

Note 2: To ensure constant junction temperature, low duty cycle pulse testing is used.

Note 3: Thermal resistance, junction to ambient, of the TO-92 (Z) Package is  $180^\circ\text{C/W}$  when mounted with 0.40 inch leads on a PC board and  $160^\circ\text{C/W}$  when mounted with 0.25 inch leads on a PC board.

**LM311 Voltage Comparator****General Description**

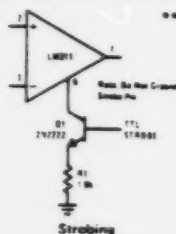
The LM311 is a voltage comparator that has input currents more than a hundred times lower than devices like the LM306 or LM710C. It is also designed to operate over a wider range of supply voltages: from standard  $\pm 15V$  op amp supplies down to the single 5V supply used for IC logic. Its output is compatible with RTL, DTL and TTL as well as MOS circuits. Further, it can drive lamps or relays, switching voltages up to 40V at currents as high as 50 mA.

**Features**

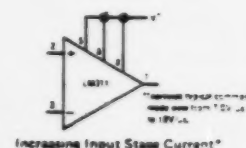
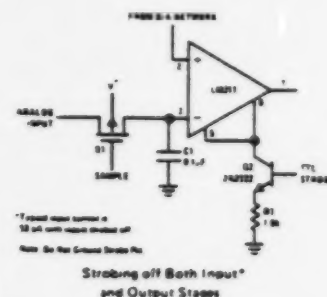
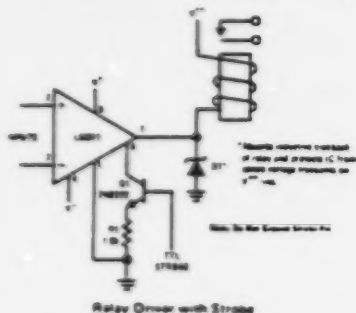
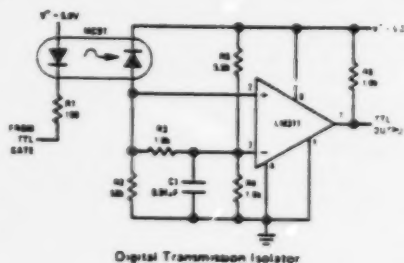
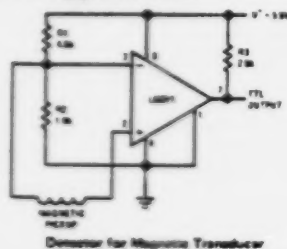
- Operates from single 5V supply
- Maximum input current: 250 nA
- Maximum offset current: 50 nA

- Differential input voltage range:  $\pm 30V$
- Power consumption: 135 mW at  $\pm 15V$

Both the input and the output of the LM311 can be isolated from system ground, and the output can drive loads referred to ground, the positive supply or the negative supply. Offset balancing and strobe capability are provided and outputs can be wire OR'ed. Although slower than the LM306 and LM710C (200 ns response time vs 40 ns), the device is also much less prone to spurious oscillations. The LM311 has the same pin configuration as the LM306 and LM710C. See the "Application hints" of the LM311 for application help.

**Auxiliary Circuits\*\***

\*\* Note: Pin connections shown on schematic diagram and typical applications are for TO-5 package

**Typical Applications\*\***



## Absolute Maximum Ratings

|                                               |                                  |
|-----------------------------------------------|----------------------------------|
| Total Supply Voltage ( $V_{+}$ )              | 36V                              |
| Output to Negative Supply Voltage ( $V_{-}$ ) | 40V                              |
| Ground to Negative Supply Voltage ( $V_{-}$ ) | 30V                              |
| Differential Input Voltage                    | $\pm 30V$                        |
| Input Voltage (Note 1)                        | $\pm 15V$                        |
| Power Dissipation (Note 2)                    | 500 mW                           |
| Output Short Circuit Duration                 | 10 sec                           |
| Operating Temperature Range                   | $0^{\circ}C$ to $70^{\circ}C$    |
| Storage Temperature Range                     | $-65^{\circ}C$ to $150^{\circ}C$ |
| Lead Temperature (soldering, 10 sec)          | $300^{\circ}C$                   |
| Voltage at Strobe Pin                         | $V^{+}-5V$                       |

## Electrical Characteristics (Note 3)

| PARAMETER                     | CONDITIONS                                                                        | MIN   | TYP       | MAX  | UNITS |
|-------------------------------|-----------------------------------------------------------------------------------|-------|-----------|------|-------|
| Input Offset Voltage (Note 4) | $T_A = 25^{\circ}C$ , $R_S \leq 50k$                                              |       | 2.0       | 7.5  | mV    |
| Input Offset Current (Note 4) | $T_A = 25^{\circ}C$                                                               |       | 6.0       | 50   | nA    |
| Input Bias Current            | $T_A = 25^{\circ}C$                                                               |       | 100       | 250  | nA    |
| Voltage Gain                  | $T_A = 25^{\circ}C$                                                               | 40    | 200       |      | V/mV  |
| Response Time (Note 5)        | $T_A = 25^{\circ}C$                                                               |       | 200       |      | ns    |
| Saturation Voltage            | $V_{IN} \leq -10$ mV, $I_{OUT} = 50$ mA<br>$T_A = 25^{\circ}C$                    |       | 0.75      | 1.5  | V     |
| Strobe ON Current             | $T_A = 25^{\circ}C$                                                               |       | 3.0       |      | mA    |
| Output Leakage Current        | $V_{IN} \geq 10$ mV, $V_{OUT} = 35V$<br>$T_A = 25^{\circ}C$ , $I_{STROBE} = 3$ mA |       | 0.2       | 50   | nA    |
| Input Offset Voltage (Note 4) | $R_S \leq 50k$                                                                    |       |           | 10   | mV    |
| Input Offset Current (Note 4) |                                                                                   |       |           | 70   | nA    |
| Input Bias Current            |                                                                                   |       |           | 300  | nA    |
| Input Voltage Range           |                                                                                   | -14.5 | 13.8-14.7 | 13.0 | V     |
| Saturation Voltage            | $V^{+} \geq 4.5V$ , $V^{-} = 0$<br>$V_{IN} \leq -10$ mV, $I_{SINK} \leq 8$ mA     |       | 0.23      | 0.4  | V     |
| Positive Supply Current       | $T_A = 25^{\circ}C$                                                               |       | 5.1       | 7.5  | mA    |
| Negative Supply Current       | $T_A = 25^{\circ}C$                                                               |       | 4.1       | 5.0  | mA    |

Note 1: This rating applies for  $\pm 15V$  supplies. The positive input voltage limit is 30V above the negative supply. The negative input voltage limit is equal to the negative supply voltage or 30V below the positive supply, whichever is less.

Note 2: The maximum junction temperature of the LM311 is  $110^{\circ}C$ . For operating at elevated temperatures, devices in the TO-8 package must be derated based on a thermal resistance of  $150^{\circ}C/W$ , junction to ambient, or  $45^{\circ}C/W$ , junction to case. The thermal resistance of the dual-in-line package is  $100^{\circ}C/W$ , junction to ambient.

Note 3: These specifications apply for  $V_S = \pm 15V$  and the Ground pin at ground, and  $0^{\circ}C < T_A < +70^{\circ}C$ , unless otherwise specified. The offset voltage, offset current and bias current specifications apply for any supply voltage from a single 5V supply up to  $\pm 15V$  supplies.

Note 4: The offset voltage and offset current given are the maximum values required to drive the output within a volt of either supply with 1 mA load. Thus, these parameters define an error band and take into account the worst-case effects of voltage gain and input impedance.

Note 5: The response time specified (see definitions) is for a 100 mV input step with 5 mV overdrive.

Note 6: Do not short the strobe pin to ground; it should be current driven at 3 to 5 mA.



## Voltage Comparators

## LM119/LM219/LM319 High Speed Dual Comparator

## General Description

The LM119 series are precision high speed dual comparators fabricated on a single monolithic chip. They are designed to operate over a wide range of supply voltages down to a single 5V logic supply and ground. Further, they have higher gain and lower input currents than devices like the LM710. The uncommitted collector of the output stage makes the LM119 compatible with RTL, DTL and TTL as well as capable of driving lamps and relays at currents up to 25 mA. Outstanding features include:

## Features

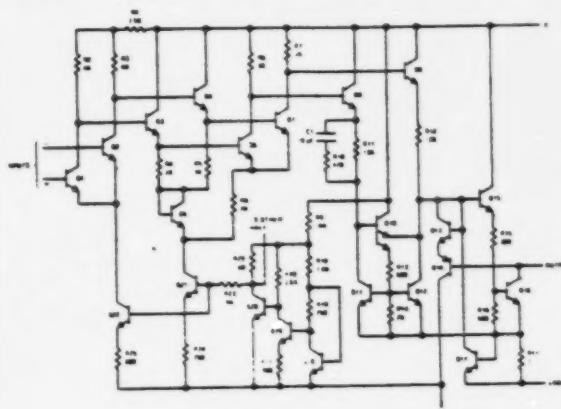
- Two independent comparators
- Operates from a single 5V supply
- Typically 80 ns response time at  $\pm 15V$
- Minimum fan-out of 2 each side

- Maximum input current of  $1 \mu A$  over temperature
- Inputs and outputs can be isolated from system ground
- High common mode slew rate

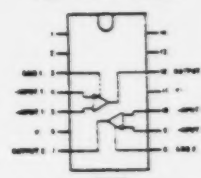
Although designed primarily for applications requiring operation from digital logic supplies, the LM119 series are fully specified for power supplies up to  $\pm 15V$ . It features faster response than the LM111 at the expense of higher power dissipation. However, the high speed, wide operating voltage range and low package count make the LM119 much more versatile than older devices like the LM711.

The LM119 is specified from  $-55^\circ C$  to  $+125^\circ C$ , the LM219 is specified from  $-25^\circ C$  to  $+85^\circ C$ , and the LM319 is specified from  $0^\circ C$  to  $+70^\circ C$ .

## Schematic and Connection Diagrams



Dual-In-Line Package



Order Number LM319N  
See NS Package N14A

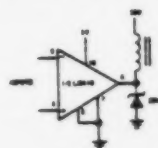
Order Number LM119J, LM219J  
or LM319J  
See NS Package J14A

Metal Can Package

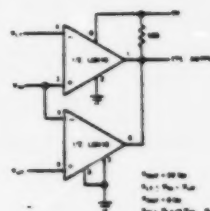


Order Number LM119H, LM219H  
or LM319H  
See NS Package H10C

## Typical Applications



Relay Driver



Window Detector

## Absolute Maximum Ratings LM319

|                                   |      |                                      |                |
|-----------------------------------|------|--------------------------------------|----------------|
| Total Supply Voltage              | 36V  | Power Dissipation (Note 2)           | 500 mW         |
| Output to Negative Supply Voltage | 36V  | Output Short-Circuit Duration        | 10 sec         |
| Ground to Negative Supply Voltage | 25V  | Operating Temperature Range: LM319   | -55°C to 70°C  |
| Ground to Positive Supply Voltage | 18V  | Storage Temperature Range            | -55°C to 150°C |
| Differential Input Voltage        | ±15V | Lead Temperature (Soldering, 10 sec) | 300°C          |
| Input Voltage (Note 1)            | ±15V |                                      |                |

## Electrical Characteristics (Note 3)

| PARAMETER                     | CONDITIONS                                                                                                    | MIN | TYP  | MAX  | UNITS         |
|-------------------------------|---------------------------------------------------------------------------------------------------------------|-----|------|------|---------------|
| Input Offset Voltage (Note 4) | $T_A = 25^\circ\text{C}$ , $R_S \leq 5k$                                                                      |     | 70   | 80   | mV            |
| Input Offset Current (Note 4) | $T_A = 25^\circ\text{C}$                                                                                      |     | 80   | 200  | nA            |
| Input Bias Current            | $T_A = 25^\circ\text{C}$                                                                                      |     | 250  | 1000 | nA            |
| Voltage Gain                  | $T_A = 25^\circ\text{C}$                                                                                      | 8   | 40   |      | V/mV          |
| Response Time (Note 5)        | $T_A = 25^\circ\text{C}$ , $V_S = \pm 15\text{V}$                                                             |     | 90   |      | ns            |
| Saturation Voltage            | $V_{IN} \leq -10\text{ mV}$ , $I_{OUT} = 25\text{ mA}$<br>$T_A = 25^\circ\text{C}$                            |     | 0.75 | 1.5  | V             |
| Output Leakage Current        | $V_{IN} \geq 10\text{ mV}$ , $V_{OUT} = 25\text{V}$<br>$V^+ = V_{DND} = 0\text{V}$ , $T_A = 25^\circ\text{C}$ |     | 0.2  | 10   | $\mu\text{A}$ |
| Input Offset Voltage (Note 4) | $R_S \leq 5k$                                                                                                 |     |      | 10   | mV            |
| Input Offset Current (Note 4) |                                                                                                               |     |      | 300  | nA            |
| Input Bias Current            |                                                                                                               |     |      | 1200 | nA            |
| Input Voltage Range           | $V_S = \pm 15\text{V}$<br>$V^+ = 5\text{V}$ , $V^- = 0$                                                       | 1   | ±13  | 3    | V             |
| Saturation Voltage            | $V^+ \geq 4.5\text{V}$ , $V^- = 0$<br>$V_{IN} \leq -10\text{ mV}$ , $I_{SINK} \leq 3.2\text{ mA}$             |     | 0.3  | 0.4  | V             |
| Differential Input Voltage    |                                                                                                               |     |      | ±5   | V             |
| Positive Supply Current       | $T_A = 25^\circ\text{C}$ , $V^+ = 5\text{V}$ , $V^- = 0$                                                      |     | 4.3  |      | mA            |
| Positive Supply Current       | $T_A = 25^\circ\text{C}$ , $V_S = \pm 15\text{V}$                                                             |     | 8    | 12.5 | mA            |
| Negative Supply Current       | $T_A = 25^\circ\text{C}$ , $V_S = \pm 15\text{V}$                                                             |     | 3    | 5    | mA            |

Note 1: For supply voltages less than  $\pm 15\text{V}$  the absolute maximum input voltage is equal to the supply voltage.

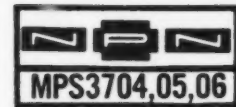
Note 2: The maximum junction temperature of the LM319 is  $85^\circ\text{C}$ . For operating at elevated temperatures, devices in the TO-5 package must be derated based on a thermal resistance of  $150^\circ\text{C/W}$ , junction to ambient, or  $45^\circ\text{C/W}$ , junction to case. The thermal resistance of the dual-in-line package is  $100^\circ\text{C/W}$ , junction to ambient.

Note 3: These specifications apply for  $V_S = \pm 15\text{V}$  and  $0^\circ\text{C} \leq T_A \leq 70^\circ\text{C}$ , unless otherwise stated. The offset voltage, offset current and bias current specifications apply for any supply voltage from a single 5V supply up to  $\pm 15\text{V}$  supplies.

Note 4: The offset voltages and offset currents given are the maximum values required to drive the output within a volt of either supply with a 1 mA load. Thus, these parameters define an error band and take into account the worst case effects of voltage gain and input impedance.

Note 5: The response time specified is for a 100 mV input step with 5 mV overdrive.

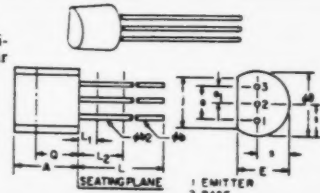
# Silicon Transistors



The General Electric MPS3704, MPS3705 and MPS3706 are silicon NPN planar, epitaxial, passivated transistors designed for general audio frequency applications and linear amplifiers. For complimentary PNP types see MPS3702 and MPS3703 specifications.

## absolute maximum ratings: ( $T_A = 25^\circ\text{C}$ unless otherwise specified)

|                                                |                | MPS3704 |             | MPS3705 |    | MPS3706 |       |
|------------------------------------------------|----------------|---------|-------------|---------|----|---------|-------|
| <b>Voltages</b>                                |                |         |             |         |    |         |       |
| Collector to Emitter                           | $V_{CEO}$      |         | 30          |         | 20 |         | Volts |
| Collector to Base                              | $V_{CBO}$      |         | 50          |         | 40 |         | Volts |
| Emitter to Base                                | $V_{EB0}$      |         | 5           |         | 5  |         | Volts |
| <b>Current</b>                                 |                |         |             |         |    |         |       |
| Collector                                      | $I_C$          |         | 600         |         |    |         | mA    |
| <b>Dissipation</b>                             |                |         |             |         |    |         |       |
| Total Power $T_A \leq 25^\circ\text{C}$        | $P_T$          |         | 350         |         |    |         | Watts |
| Total Power $T_C \leq 25^\circ\text{C}$        | $P_T$          |         | 1.0         |         |    |         | Watts |
| Derate Factor $T_A > 25^\circ\text{C}$         |                |         | 2.8         |         |    |         | mW/°C |
| Derate Factor $T_C > 25^\circ\text{C}$         |                |         | 8.0         |         |    |         | mW/°C |
| <b>Temperature</b>                             |                |         |             |         |    |         |       |
| Storage and Operating                          | $T_{STG}, T_J$ |         | -55 to +150 |         |    |         | °C    |
| Lead (1.16" $\pm$ 1.32" from case for 10 sec.) | $T_L$          |         | +260        |         |    |         | °C    |



|        |  | TO-92       |      |        |       |
|--------|--|-------------|------|--------|-------|
|        |  | MILLIMETERS |      | INCHES |       |
| SYMBOL |  | MIN         | MAX  | MIN    | MAX   |
| A      |  | 4.32        | 5.33 | 0.170  | 0.210 |
| a      |  | 4.07        | 5.30 | 0.160  | 0.210 |
| b      |  | 4.07        | 4.82 | 0.160  | 0.190 |
| c      |  | 4.45        | 5.20 | 0.175  | 0.205 |
| E      |  | 3.18        | 4.19 | 0.125  | 0.165 |
| e      |  | 2.41        | 2.67 | 0.095  | 0.105 |
| f      |  | 1.50        | 1.39 | 0.045  | 0.055 |
| L      |  | 3.43        | 4.32 | 0.135  | 0.170 |
| L1     |  | 32.70       | —    | 500    | —     |
| L2     |  | —           | 1.27 | —      | 0.050 |
| Q      |  | 4.33        | —    | 2.50   | —     |
| Q1     |  | 2.92        | —    | 1.15   | —     |
| s      |  | 2.03        | 2.67 | 0.080  | 0.105 |

NOTES:  
1 THREE LEADS  
2 CONTOUR OF PACKAGE UNCONTROLLED OUTSIDE THIS SIDE  
3 (THREE LEADS) 90° APPLIES BETWEEN L1 AND L2  
a) APPLIES BETWEEN L2 AND 12.70 MM (500") FROM THE SEATING PLANE. DIAMETER IS UNCONTROLLED IN L1 AND BEYOND (2.70 MM (500") FROM SEATING PLANE.

## electrical characteristics: ( $T_A = 25^\circ\text{C}$ unless otherwise specified)

|                                                                                                       |               | MPS3704 |      | MPS3705 |      | MPS3706 |      | Units |
|-------------------------------------------------------------------------------------------------------|---------------|---------|------|---------|------|---------|------|-------|
| STATIC CHARACTERISTICS                                                                                |               | Min.    | Max. | Min.    | Max. | Min.    | Max. |       |
| Collector-Emitter Breakdown Voltage<br>( $I_C = 10\text{mA}$ , $I_B = 0$ )                            | $V_{(BR)CEO}$ | 30      |      | 30      |      | 20      |      | Volts |
| Collector-Base Breakdown Voltage<br>( $I_C = 100\text{uA}$ , $I_E = 0$ )                              | $V_{(BR)CBO}$ | 50      |      | 50      |      | 40      |      | Volts |
| Emitter-Base Breakdown Voltage<br>( $I_E = 100\text{uA}$ , $I_C = 0$ )                                | $V_{(BR)EBO}$ | 5       |      | 5       |      | 5       |      | Volts |
| Collector Cutoff Current<br>( $V_{CB} = 20\text{V}$ , $I_E = 0$ )                                     | $I_{CBO}$     |         | 100  |         | 100  |         | 100  | nA    |
| Emitter-Base Reverse Current<br>( $V_{EB} = 3\text{V}$ , $I_C = 0$ )                                  | $I_{EBO}$     |         | 100  |         | 100  |         | 100  | nA    |
| Forward Current Transfer Ratio<br>( $V_{CE} = 2\text{V}$ , $I_C = 50\text{mA}$ )                      | $h_{FE}$      | 100     | 300  | 50      | 150  | 30      | 600  |       |
| Collector-Emitter Saturation Voltage<br>( $I_C = 100\text{mA}$ , $I_B = 5\text{mA}$ )                 | $V_{CE(SAT)}$ |         | .6   |         | .8   |         | 1    | Volts |
| Base-Emitter Voltage<br>( $V_{CE} = 2\text{V}$ , $I_C = 100\text{mA}$ )                               | $V_{BE(ON)}$  | .5      | 1    | .5      | 1    | .5      | 1    | Volts |
| DYNAMIC CHARACTERISTICS                                                                               |               |         |      |         |      |         |      |       |
| Collector-Base Capacitance<br>( $V_{CB} = 10\text{V}$ , $I_E = 0$ , $f = 1\text{MHz}$ )               | $C_{in}$      |         | 12   |         | 12   |         | 12   | pf    |
| Current Gain-Bandwidth Product<br>( $V_{CE} = 2\text{V}$ , $I_C = 50\text{mA}$ , $f = 20\text{MHz}$ ) | $f_T$         | 100     |      | 100     |      | 100     |      | MHz   |

\*Pulse Conditions: Pulse Width  $\leq 300\text{us}$  and duty cycle  $\leq 2\%$

# **2N4924 (SILICON)** **2N4925**

... NPN silicon annular transistors designed for high-voltage, high-frequency amplifier applications.



**CASE 79  
(TO-39)**  
Collector  
connected to case

## **MAXIMUM RATINGS**

| Rating                                                                               | Symbol    | 2N4924      | 2N4925 | Unit                      |
|--------------------------------------------------------------------------------------|-----------|-------------|--------|---------------------------|
| Collector-Emitter Voltage                                                            | $V_{CEO}$ | 100         | 150    | Vdc                       |
| Collector-Base Voltage                                                               | $V_{CB}$  | 100         | 150    | Vdc                       |
| Emitter-Base Voltage                                                                 | $V_{EB}$  | 5.0         |        | Vdc                       |
| Collector Current - Continuous                                                       | $I_C$     | 200         |        | mA dc                     |
| Total Device Dissipation $T_A = 25^\circ\text{C}$<br>Derate above $25^\circ\text{C}$ | $P_D$     | 1.0<br>5.71 |        | W<br>mW/ $^\circ\text{C}$ |
| Total Device Dissipation $T_C = 25^\circ\text{C}$<br>Derate above $25^\circ\text{C}$ | $P_D$     | 5.0<br>28.6 |        | W<br>mW/ $^\circ\text{C}$ |
| Operating Junction Temperature Range                                                 | $T_J$     | -65 to +175 |        | $^\circ\text{C}$          |
| Storage Temperature Range                                                            | $T_{stg}$ | -65 to +200 |        | $^\circ\text{C}$          |

## **ELECTRICAL CHARACTERISTICS** ( $T_A = 25^\circ\text{C}$ unless otherwise noted)

| Characteristic | Symbol | Min | Max | Unit |
|----------------|--------|-----|-----|------|
|----------------|--------|-----|-----|------|

### **OFF CHARACTERISTICS**

|                                                                                                                    |                  |            |            |            |                  |
|--------------------------------------------------------------------------------------------------------------------|------------------|------------|------------|------------|------------------|
| Collector-Emitter Breakdown Voltage <sup>(1)</sup><br>( $I_C = 10 \text{ mA dc}$ , $I_B = 0$ )                     | 2N4924<br>2N4925 | $BV_{CEO}$ | 100<br>150 | -          | Vdc              |
| Collector-Base Breakdown Voltage<br>( $I_C = 100 \mu\text{A dc}$ , $I_E = 0$ )                                     | 2N4924<br>2N4925 | $BV_{CBO}$ | 100<br>150 | -          | Vdc              |
| Emitter-Base Breakdown Voltage<br>( $I_E = 100 \mu\text{A dc}$ , $I_C = 0$ )                                       |                  | $BV_{EBO}$ | 5.0        | -          | Vdc              |
| Collector Cutoff Current<br>( $V_{CB} = 50 \text{ Vdc}$ , $I_E = 0$ )<br>( $V_{CB} = 75 \text{ Vdc}$ , $I_E = 0$ ) |                  | $I_{CBO}$  | -<br>-     | 0.1<br>0.1 | $\mu\text{A dc}$ |

### **ON CHARACTERISTICS <sup>(1)</sup>**

|                                                                                                                                                                                                       |               |                |               |  |     |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----------------|---------------|--|-----|
| DC Current Gain<br>( $I_C = 1.0 \text{ mA dc}$ , $V_{CE} = 10 \text{ Vdc}$ )<br>( $I_C = 10 \text{ mA dc}$ , $V_{CE} = 10 \text{ Vdc}$ )<br>( $I_C = 150 \text{ mA dc}$ , $V_{CE} = 10 \text{ Vdc}$ ) | $h_{FE}$      | 25<br>35<br>40 | -<br>-<br>200 |  |     |
| Collector-Emitter Saturation Voltage<br>( $I_C = 10 \text{ mA dc}$ , $I_B = 1.0 \text{ mA dc}$ )<br>( $I_C = 50 \text{ mA dc}$ , $I_B = 5.0 \text{ mA dc}$ )                                          | $V_{CE(sat)}$ | -<br>-         | 0.25<br>0.4   |  | Vdc |
| Base-Emitter On Voltage<br>( $I_C = 50 \text{ mA dc}$ , $V_{CE} = 10 \text{ Vdc}$ )                                                                                                                   | $V_{BE(on)}$  | -              | 0.95          |  | Vdc |

### **DYNAMIC CHARACTERISTICS**

|                                                                                                                      |          |     |     |  |     |
|----------------------------------------------------------------------------------------------------------------------|----------|-----|-----|--|-----|
| Current-Gain - Bandwidth Product<br>( $I_C = 20 \text{ mA dc}$ , $V_{CE} = 20 \text{ Vdc}$ , $f = 100 \text{ MHz}$ ) | $f_T$    | 100 | 500 |  | MHz |
| Collector-Base Capacitance<br>( $V_{CB} = 20 \text{ Vdc}$ , $I_E = 0$ , $f = 100 \text{ kHz}$ )                      | $C_{cb}$ | -   | 10  |  | pF  |
| Collector-Emitter Capacitance<br>( $V_{BE} = 1.0 \text{ Vdc}$ , $I_C = 0$ , $f = 100 \text{ kHz}$ )                  | $C_{eb}$ | -   | 80  |  | pF  |

<sup>(1)</sup> Pulse Test Pulse Width  $\leq 300 \mu\text{s}$ , Duty Cycle  $\leq 2.0\%$ .

# DC-DC converters

This broad line of DC-DC converters features 33 one-watt models with single and dual output voltages. Input voltages are 5, 12, 24, 28 and 48 with single outputs of 5, 12, 15, 24, and 28 and dual outputs of  $\pm 12$ ,  $\pm 15$ , and  $\pm 18$ V. Output voltage accuracies are  $\pm 1\%$  with  $0.02\%/^{\circ}\text{C}$  temperature coefficients. Other features include low output ripple, 100 megohm isolation, and output current limiting.

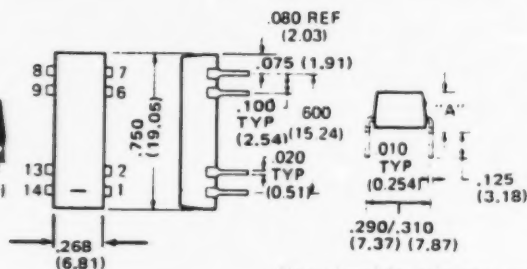
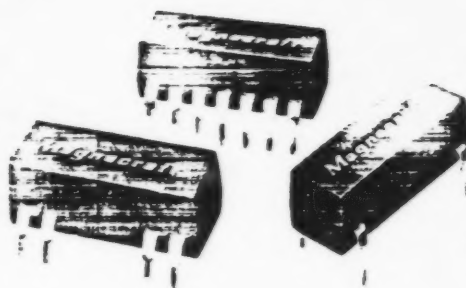


## 1 watt series

| MODEL NO.     | OUTPUT VOLTAGE | OUTPUT CURRENT | INPUT VOLTAGE       | EFFIC. (FULL LOAD) | LINE/LOAD REGULATION | COMMENTS                                                                                                                                                                                                                                                                                                                                        |
|---------------|----------------|----------------|---------------------|--------------------|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| UPM-5/200-D5  | +5 V           | 200 mA         | 5 VDC $\pm 10\%$    | 40%                | 0.05%/0.1%           | 1 watt series of DC-DC converters. Case size is 1.5 x 2.0 x 0.375 (in). Tempco is $0.02\%/^{\circ}\text{C}$ ; output impedance is $0.07\ \Omega$ or $0.02\ \Omega$ and output noise and ripple is 2 mV RMS. Output voltage accuracy is within $\pm 1\%$ and the operating temperature range is $-25^{\circ}\text{C}$ to $+71^{\circ}\text{C}$ . |
| UPM-5/200-D12 | +5 V           | 200 mA         | 12 VDC $\pm 10\%$   | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-5/200-D24 | +5 V           | 200 mA         | 24 VDC $\pm 10\%$   | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-5/200-D28 | +5 V           | 200 mA         | 28 VDC $\pm 10\%$   | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-5/200-D48 | +5 V           | 200 mA         | 48 VDC $\pm 12.5\%$ | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-12/80-D5  | +12 V          | 80 mA          | 5 VDC $\pm 10\%$    | 50%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-12/80-D24 | +12 V          | 80 mA          | 24 VDC $\pm 10\%$   | 50%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-12/80-D28 | +12 V          | 80 mA          | 28 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-12/80-D48 | +12 V          | 80 mA          | 48 VDC $\pm 12.5\%$ | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-15/60-D5  | +15 V          | 60 mA          | 5 VDC $\pm 10\%$    | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-15/60-D12 | +15 V          | 60 mA          | 12 VDC $\pm 10\%$   | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-15/60-D24 | +15 V          | 60 mA          | 24 VDC $\pm 10\%$   | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-15/60-D28 | +15 V          | 60 mA          | 28 VDC $\pm 10\%$   | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-15/60-D48 | +15 V          | 60 mA          | 48 VDC $\pm 12.5\%$ | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-24/40-D5  | +24 V          | 40 mA          | 5 VDC $\pm 10\%$    | 50%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-24/40-D12 | +24 V          | 40 mA          | 12 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-28/25-D5  | +28 V          | 25 mA          | 5 VDC $\pm 10\%$    | 50%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| UPM-28/25-D12 | +28 V          | 25 mA          | 12 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-12/25-D5  | $\pm 12$ V     | 25 mA          | 5 VDC $\pm 10\%$    | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-12/25-D12 | $\pm 12$ V     | 25 mA          | 12 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-12/25-D24 | $\pm 12$ V     | 25 mA          | 24 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-12/25-D28 | $\pm 12$ V     | 25 mA          | 28 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-12/40-D48 | $\pm 12$ V     | 40 mA          | 48 VDC $\pm 12.5\%$ | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-15/25-D5  | $\pm 15$ V     | 25 mA          | 5 VDC $\pm 10\%$    | 50%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-15/25-D12 | $\pm 15$ V     | 25 mA          | 12 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-15/25-D24 | $\pm 15$ V     | 25 mA          | 24 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-15/25-D28 | $\pm 15$ V     | 25 mA          | 28 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-15/30-D48 | $\pm 15$ V     | 30 mA          | 48 VDC $\pm 12.5\%$ | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-18/25-D5  | $\pm 18$ V     | 25 mA          | 5 VDC $\pm 10\%$    | 50%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-18/25-D12 | $\pm 18$ V     | 25 mA          | 12 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-18/25-D24 | $\pm 18$ V     | 25 mA          | 24 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-18/25-D28 | $\pm 18$ V     | 25 mA          | 28 VDC $\pm 10\%$   | 55%                | 0.05%/0.05%          |                                                                                                                                                                                                                                                                                                                                                 |
| BPM-18/25-D48 | $\pm 18$ V     | 25 mA          | 48 VDC $\pm 12.5\%$ | 50%                | 0.05%/0.1%           |                                                                                                                                                                                                                                                                                                                                                 |



# SPST-NO (FORM A)



Note: (mm) for reference only.

| CLASS | "A" HEIGHT  |
|-------|-------------|
| 107   | .210 (5.33) |
| 117   | .210 (5.33) |
| 118   | .210 (5.33) |
| 171   | .275 (6.99) |
| 172   | .275 (6.99) |
| 173   | .275 (6.99) |
| 174   | .275 (6.99) |
| 176   | .275 (6.99) |
| 177   | .275 (6.99) |

## PART NUMBER (W prefix indicates stock item)

## ALL VALUES AT 25°C

| NO. DIODE        | WITH ELECTRO-STATIC SHIELD | WITH DIODE | WITH DIODE & ELECTRO-STATIC SHIELD | COIL OHMS ±10%                                          | MAX. PICK UP VDC | MIN. DROP OUT VDC | NOM. COIL VDC | NOM. COIL POWER MW | "A" HEIGHT |
|------------------|----------------------------|------------|------------------------------------|---------------------------------------------------------|------------------|-------------------|---------------|--------------------|------------|
| FORM A (SPST-NO) |                            |            |                                    | Contact Rating: 10VA max., .5 amps max., or 100VDC max. |                  |                   |               |                    |            |
| WD27             |                            |            |                                    |                                                         |                  |                   |               |                    |            |
| W107DIP-1        | N/A                        | W107DIP-5  | N/A                                | 500                                                     | 3.8              | .5                | 5             | 50                 | .210       |
| W107DIP-2        | N/A                        | W107DIP-6  | N/A                                | 500                                                     | 4.5              | .5                | 6             | 75                 | .210       |
| W107DIP-3        | N/A                        | W107DIP-7  | N/A                                | 500                                                     | 9.0              | .5                | 12            | 300                | .210       |
| W107DIP-4        | N/A                        | W107DIP-8  | N/A                                | 1200                                                    | 18.0             | .5                | 24            | 500                | .210       |

|                  |            |            |            |                                                         |      |    |    |     |      |
|------------------|------------|------------|------------|---------------------------------------------------------|------|----|----|-----|------|
| FORM A (SPST-NO) |            |            |            | Contact Rating: 10VA max., .5 amps max., or 100VDC max. |      |    |    |     |      |
| WD36             |            |            |            |                                                         |      |    |    |     |      |
| W117DIP-68       | 117DIP-82  | W117DIP-70 | N/A        | 500                                                     | 3.8  | .5 | 5  | 50  | .210 |
| W117DIP-69       | 117DIP-83  | W117DIP-71 | N/A        | 500                                                     | 4.5  | .5 | 6  | 75  | .210 |
| W117DIP-3        | 117DIP-76  | W117DIP-7  | N/A        | 500                                                     | 9.0  | .5 | 12 | 300 | .210 |
| W117DIP-4        | 117DIP-77  | W117DIP-8  | N/A        | 1200                                                    | 18.0 | .5 | 24 | 500 | .210 |
| WD46             |            |            |            |                                                         |      |    |    |     |      |
| W171DIP-2        | 171DIP-115 | W171DIP-7  | 171DIP-120 | 500                                                     | 3.8  | .5 | 5  | 50  | .275 |
| W171DIP-3        | 171DIP-116 | W171DIP-8  | 171DIP-121 | 500                                                     | 4.5  | .5 | 6  | 75  | .275 |
| W171DIP-4        | 171DIP-117 | W171DIP-9  | 171DIP-122 | 500                                                     | 9.0  | .5 | 12 | 290 | .275 |
| W171DIP-5        | 171DIP-118 | W171DIP-10 | 171DIP-123 | 2200                                                    | 18.0 | .5 | 24 | 270 | .275 |

Note: All engineering data subject to change without notice.

## MERCURY-WETTED CONTACT RELAYS

SPDT LOW PROFILE SINGLE-SIDE-STABLE

SPDT STANDARD SINGLE-SIDE-STABLEDPDT STANDARD LOW THERMAL SINGLE-SIDE-STABLE (C.O.T.)SPDT STANDARD BISTABLE (DOUBLE WOUND COIL)

SCREENED PART NUMBERS ARE STOCK RELAYS



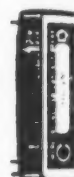
**LOW PROFILE**



HGLM



HGJ2MT



HGJM

**CONTACT RATING (Resistive Load):**

|         |                       |
|---------|-----------------------|
| Power   | 100 VA, max.          |
| Voltage | 500 V, dc or ac, max. |
| Current | 2A, switched, max.    |
|         | 5A, carry only, max.  |

**CONTACT FORMS:**

|        |          |
|--------|----------|
| HGJM   | 1 Form C |
| HGJ2MT | 2 Form C |

CONTACT RESISTANCE (ON Impedance):

15 to 25 milliohms,  $\pm 2.0$  milliohms

## DRAIN TIME:

45 seconds after reaching vertical position.

**LIFE EXPECTANCY:**

Greater than  $10 \times 10^9$  operations at rated load with proper contact protection

OPERATE TIME:

1.25 ms. response time  
Switching up to 250 Hz (4.0 ms period)

**BREAKDOWN VOLTAGE:**

1,000 V. rms 60 Hz minimum between all mutually insulated terminals, except between windings of double wound coils, 200 Vdc.

## INSULATION RESISTANCE (OFF Impedance):

|               | Standard Value | Available (Note 4) |
|---------------|----------------|--------------------|
| HGJM Series   | 100 megohms    | 100,000 megohms    |
| HGJ2MT Series | 10,000 megohms | 100,000 megohms    |

(Measured across open contacts at 25°C., 40% relative humidity.)

MODULE CAPACITANCE:

|                        | Standard<br>HGJM | Low Profile<br>HGJM | Low<br>Thermal<br>HGJ2MT |
|------------------------|------------------|---------------------|--------------------------|
| Across Open Contacts   | 4.0 pF           | 3.0 pF              | 2.5 pF                   |
| Open Contact to Coil   | 5.0 pF           | 4.0 pF              | 1.0 pF                   |
| Closed Contact to Coil | 10.0 pF          | 8.0 pF              | 1.5 pF                   |

TRANSFER OPEN TIME:

25 microseconds minimum

COMMON OPEN TIME:

Standard HGJ2MT relays have COT of 50  $\mu$ s at 100 Hz., 50% duty cycle.

Also available without COT on request.

COIL POWER DISSIPATION (at 25° C):

1.75 W max. HGJM  
3.5 W max. HGJ2MT

**ENVIRONMENTAL:**

**Vibration:** 10 to 500 Hz 0.06" d.a. or 5 g's  
**Shock:** 30 g 11 ± 1 ms., ½ sinewave  
 (Non-operating)  
**Temperature:** -38° C to +105° C. (operating)

## PHYSICAL

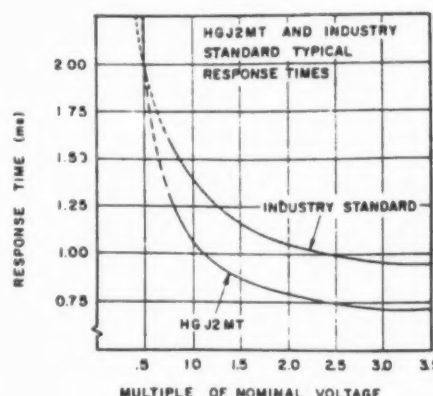
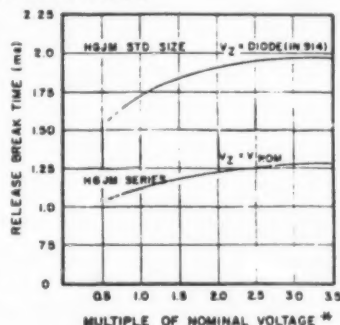
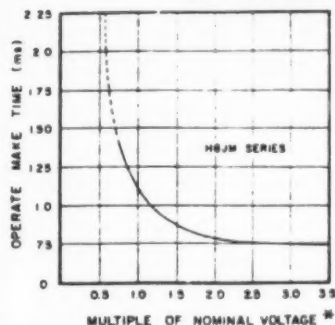
|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| Mounting | Upright within 30° of vertical                                             |
| Cover    | Plated steel cover, cadmium iridite finish                                 |
| Base     | Thermo-setting electrical grade plastic                                    |
| Pins     | Brass, gold plated, .025" diameter                                         |
| Weight   | Low Profile—4 oz. HGJM, .7 oz. HGJMT<br>Standard—5 oz. HGJM, 1.0 oz. HGJMT |

## NOTES:

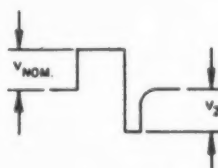
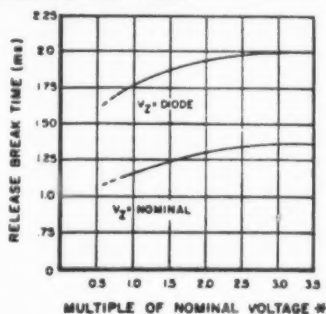
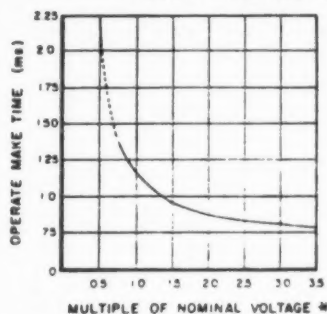
1. All operating characteristics at 25° C.
2. All dimensions in inches.
3. Electrostatic shields available on request.
4. Contact a Clare Sales C"co for additional information.

# TIMING CHARTS

## TYPICAL RESPONSE TIMES — HGJM SINGLE-SIDE-STABLE



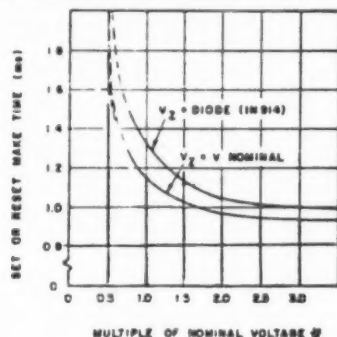
## TYPICAL RESPONSE TIMES — HGJ2MT SERIES SINGLE-SIDE-STABLE



### NOTES:

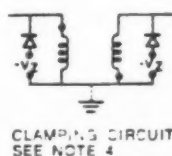
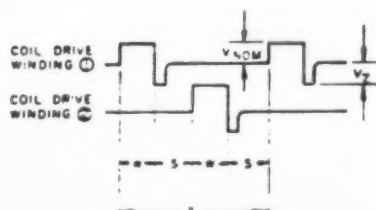
- Response time measurements made at 100 Hz, 50% duty cycle square-wave coil drive.
- Graphs are typical of response times over the entire coil resistance range.
- $V_Z$  is the value to which the reverse coil voltage is clamped.
- \*These relays have been designed for dynamic performance up to 250 Hz when operated at the recommended nominal supply voltage and driven:
  - from a source with a rise time of less than 1 microsecond;
  - when an ON time of 2 milliseconds or more;
  - with an OFF time of 2 milliseconds or more;
  - with the reverse coil voltage, generated by the collapsing magnetic field, clamped (limited) to a value greater than or equal to nominal voltage.

## TYPICAL RESPONSE TIMES — HGJM BISTABLE



### NOTES:

- Response time taken with  $w = 5$  ms,  $s = 0$  ( $f = 100$  Hz).
- Graphs are typical of response times over the entire coil resistance range.
- $V_Z$  is the value to which the reverse coil voltage is clamped.
- \*These relays are designed for dynamic performance up to 250 Hz. ( $T \geq 4.0$  ms) when operated at the recommended nominal supply voltage and driven:
  - from a source with a rise time of less than 1 microsecond;
  - with pulse widths,  $w$ , greater than or equal to 1.5 millisecond ( $w \geq 1.5$  ms);
  - with spacing between the pulses in each winding,  $s$ , greater than or equal to zero ( $s \geq 0$ );
  - with the reverse coil voltage, generated by the collapsing magnetic field, clamped (limited) to a value greater than or equal to nominal voltage. For nominal voltage relays under 12 volts,  $V_Z$  must not be less than 12 volts to attain 250 Hz without the sacrifice of additional power input.



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